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On the Origin of the Neogene Volcanic Series in Southwest Japan.

Takashi MATSUMOTO.

Abstract: The writer has proposed A-C-N diagram for the considerations of petrogenesis in volcanic rocks. Based upon the trends of Al-Ca-Na ratios of volcanic rocks represented on this diagram, it is suggested that crystallization differentiation of magmas would play secondary role in determining the diversities in volcanic rocks.

On the other hand, Neogene volcanic series in Southwest Japan are classified depending upon the tectogenetical stages and geologic provinces. In this case, each volcanic series is characterized by definite rock series, the A-C-N ratios of which generally suggest that the diversities of rocks in the same volcanic series can not be explained by the differentiation of common parental magma.

Thus, it would be concluded that the petrographic characters of Neogene volcanic sevies concerned are essentially determined by the physical and chemical conditions, under which magmas are generated.

1. Introduction

The considerations on petrogenesis of volcanic rocks seem to have been based essentially upon the concept of magmatic differentiation of parental magmas. Thus, the concept of petrographic province is often considered to be a synonym of the concept of comagmatic province.

In the course of his study on the Neogene volcanic activities especially in the Southwest Japan, the writer has realized that the petrogenetical considerations could not be made apart from tectogenesis, and that petrographic province would not necessarily be a synonym of comagmatic province.

It would be true that the magmatic differentiation and assimilation take place in one definite magma reservoir. But, this seems not to mean that the petrogenesis in general can be explained by the phenomena occurring in the course of the solidification of magmas.

In this article, these points will be discussed in the case of Neogene volcanic activities in the Southwest Japan from petrochemical and geotectonical view-points.

2. Rock series and Al-Ca-Na ratio in volcanic rocks

The writer has suggested that Al–Ca–Na ratio in igneous rocks has important implications in consideration on the origin of rock series. His proposal of A-C-N diagram has been based upon this suggestion (MATSUMOTO. 1957). In this

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section, some revised discussions on this diagram will be given.

In A-C-N diagram, each apex of triangular diagram is chosen to represent Al, Ca and Na as 100% in atomic ratio respectively. On this diagram, Al-Ca-Na ratios calculated from the bulk chemical composition of igneous are represented. In Fig. 1,

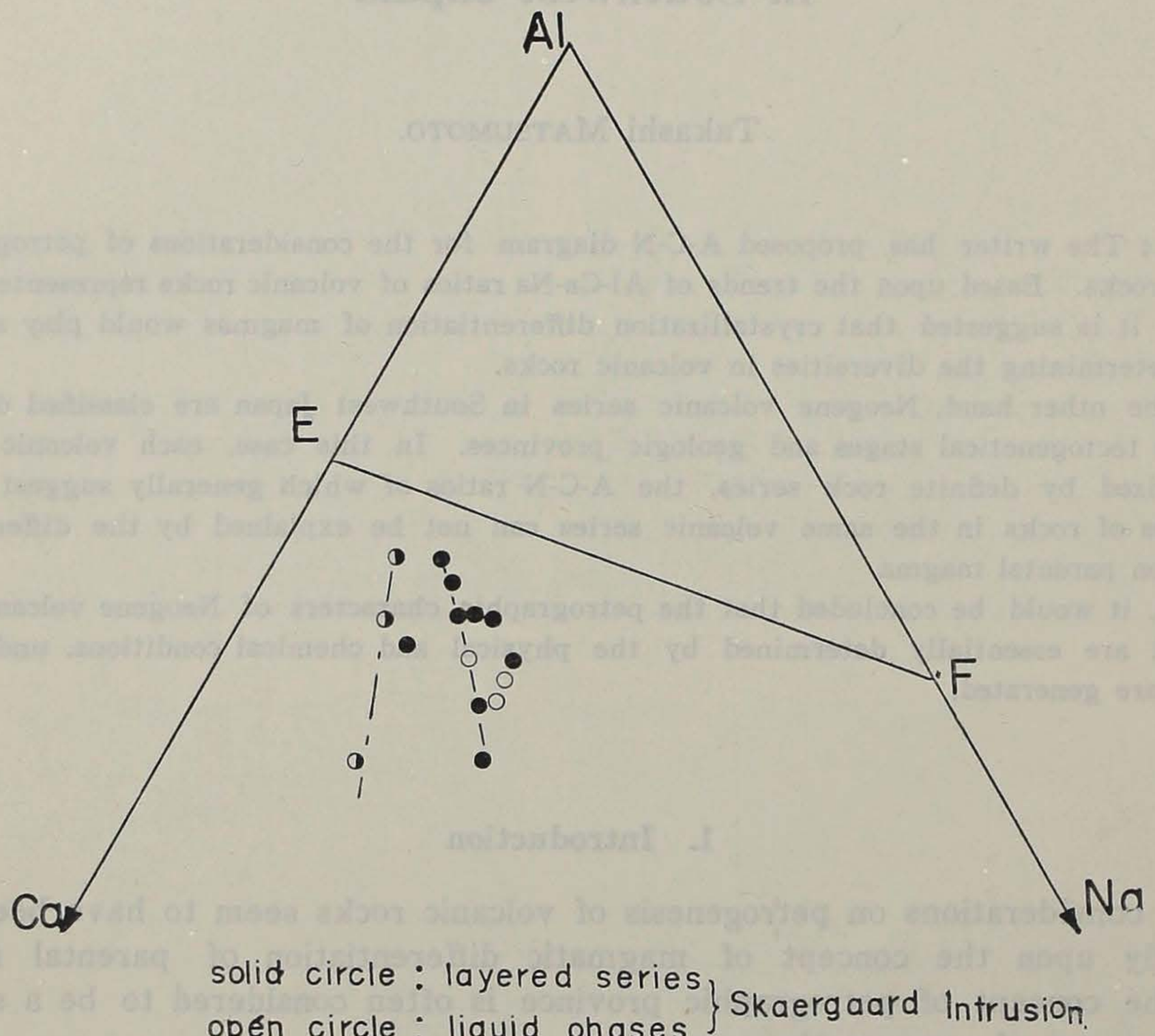
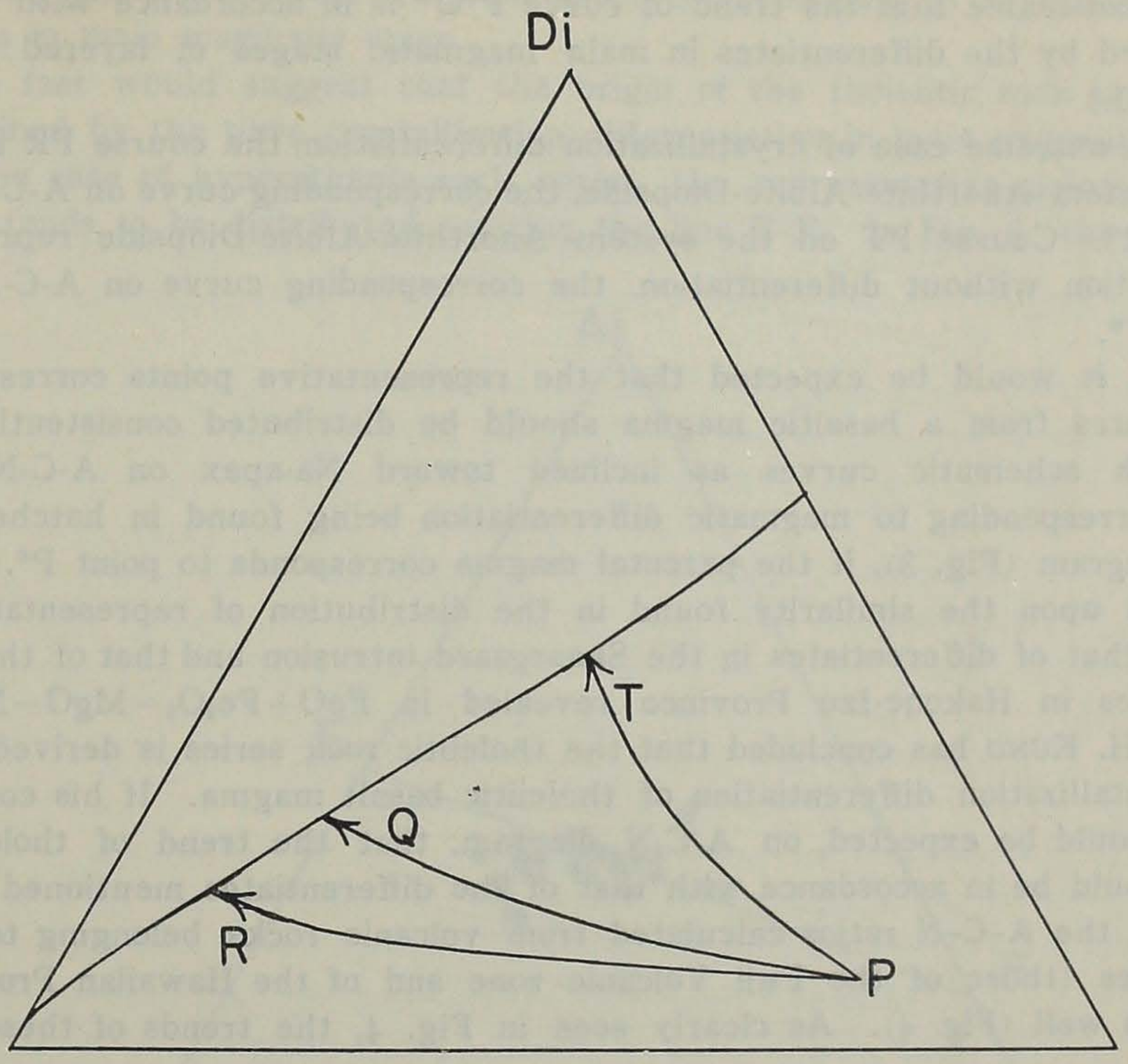


Fig. A-C-N ratios of layered intrusives

line E-F corresponds to the variation of Al-Ca-Na ratio in the solid solution of plagioclase. The point E corresponds to anorthite and F corresponds to albite respectively.

As typical examples of crystallization differentiation, the writer has selected the cases of the Skaergaard intrusion and the Bushveld lopolith, the representative points in their differentiates being plotted on this diagram (Fig. 1.). On the other hand, in order to examine tentatively the course of crystallization differentiation from a dry magma, a hypothetical perental magma, A-C-N ratio of which is similar to that of the layered intrusions above cited, is assumed to be represented by point P on the system Albite-Anorthite-Diopside (Fig. 2.). On this diagram, line PQ is assumed as to show one of the courses of crystallization differentiation. On A-C-N diagram, this course corresponds to the curve P* Q* by recalculation (Fig. 3).



Courses of the crystallization

Fig 2. in the system Di – Ab – An

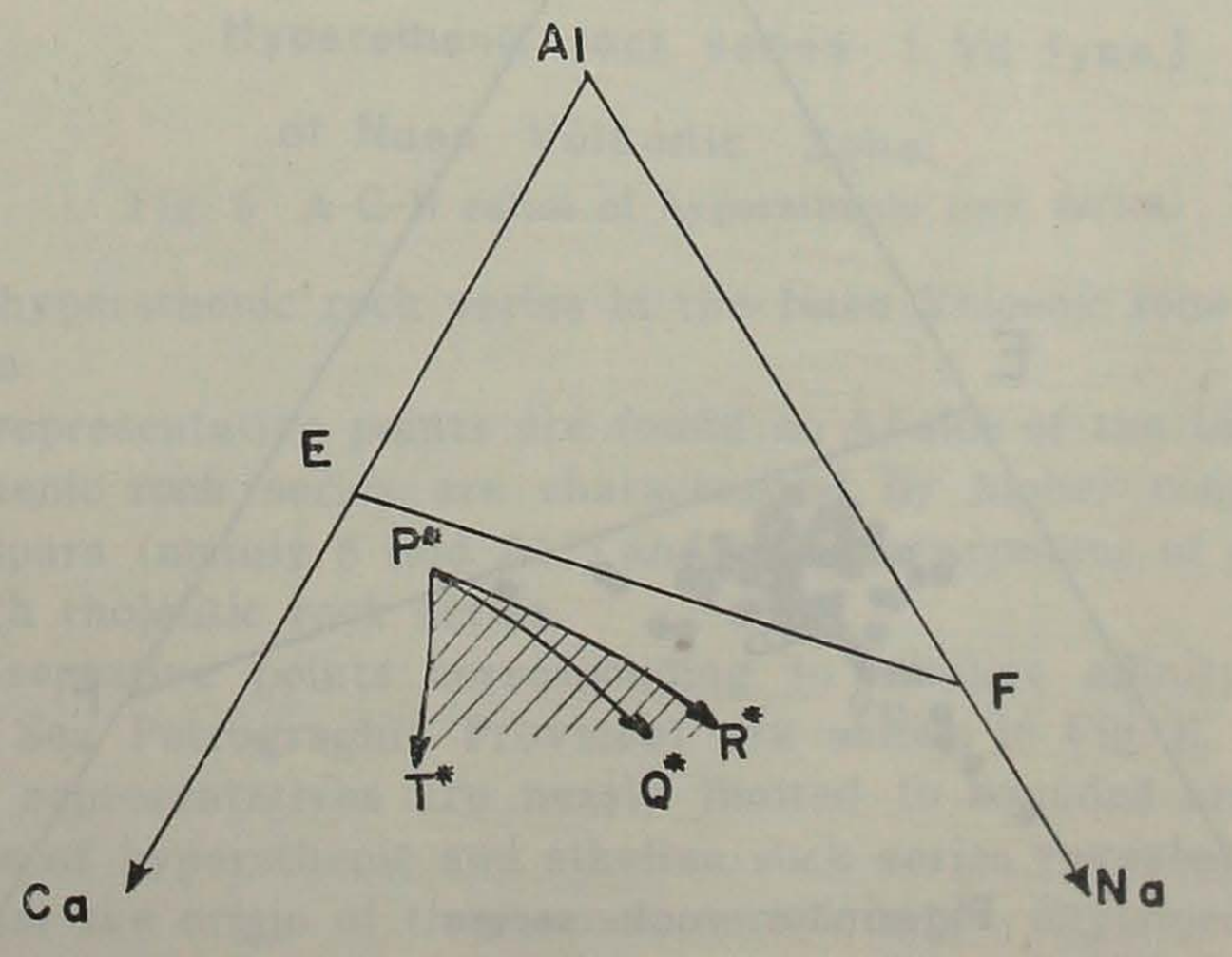


Fig. 3. Schematic trend of differentiates of hypothetical magma.

It is noticeable that the trend of curve P*Q* is in accordance with the trends represented by the differentiates in main magmatic stages of layered intrusions. (see Fig. 1.)

As an extreme case of crystallization differentiation, the course PR is assumed on the system Anorthite-Albite-Diopside, the corresponding curve on A-C-N diagram being P*R*. Course PT on the system Anorthite-Albite-Diopside represents the crystallization without differentiation, the corresponding curve on A-C-N diagram being P*T*.

Thus, it would be expected that the representative points corresponding to differentiates from a basaltic magma should be distributed consistently in trend with such schematic curves as inclined toward Na-apex on A-C-N diagram, curves corresponding to magmatic differentiation being found in hatched area on A-C-N diagram (Fig. 3), if the parental magma corresponds to point P*.

Based upon the similarity found in the distribution of representative points between that of differentiates in the Skaergaard intrusion and that of the tholeiitic rock series in Hakone-Izu Province revealed in $FeO+Fe_2O_3-MgO-Na_2O+K_2O$ diagram, H. KUNO has concluded that the tholeiitic rock series is derived from the pure crystallization differentiation of tholeiitic basalt magma. If his conclusion is true, it would be expected, on A-C-N diagram, that the trend of tholeiitic rock series should be in accordance with that of the differentiates mentioned above.

Then, the A–C–N ratios calculated from volcanic rocks belonging to tholeiitic rock series (those of the Fuji Volcanic zone and of the Hawaiian Province) are plotted as well (Fig. 4). As clearly seen in Fig. 4, the trends of these rocks on

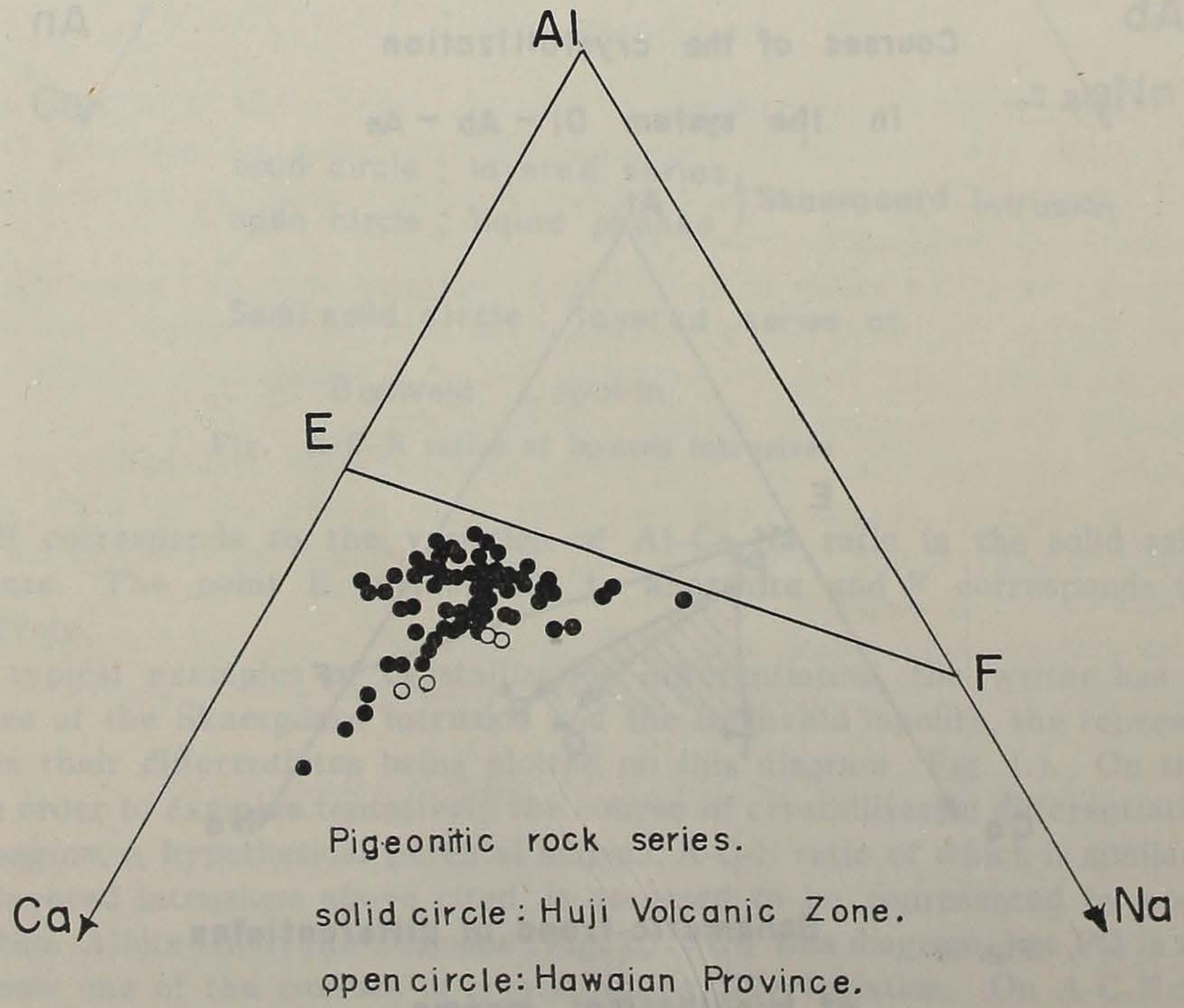


Fig. 4. A–C–N ratios of tholeiitic rock series.

A-C-N diagram are different from the trend corresponding to crystallization differentiation in main magmatic stage.

This fact would suggest that the origin of the tholeiitic rock series can not be explained by the pure crystallization differentiation in main magmatic stage.

In the case of hypersthenic rock series, the representative points on A-C-N diagram tends to be distributed crossing the line E-F. In Fig. 5, the representa-

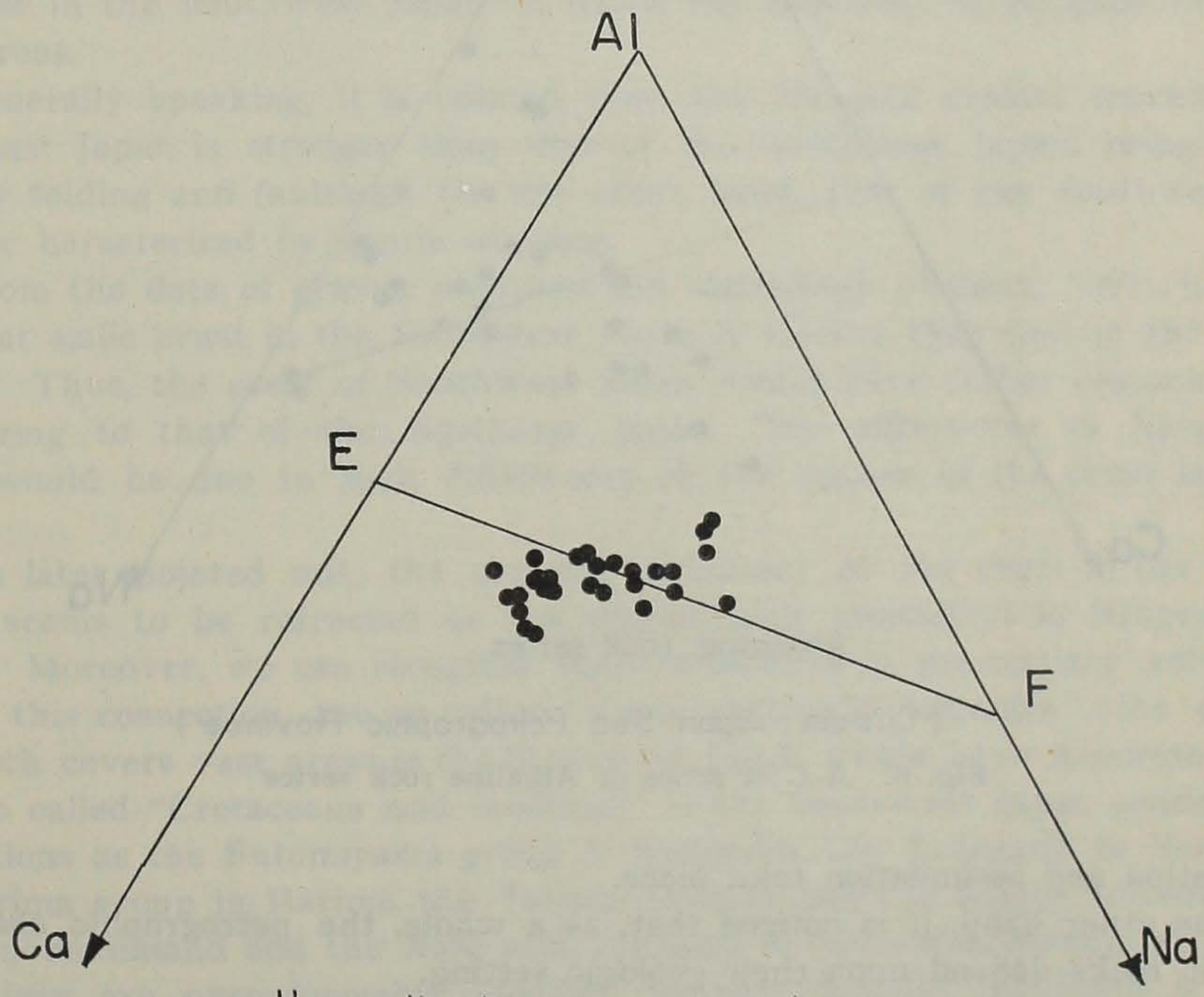


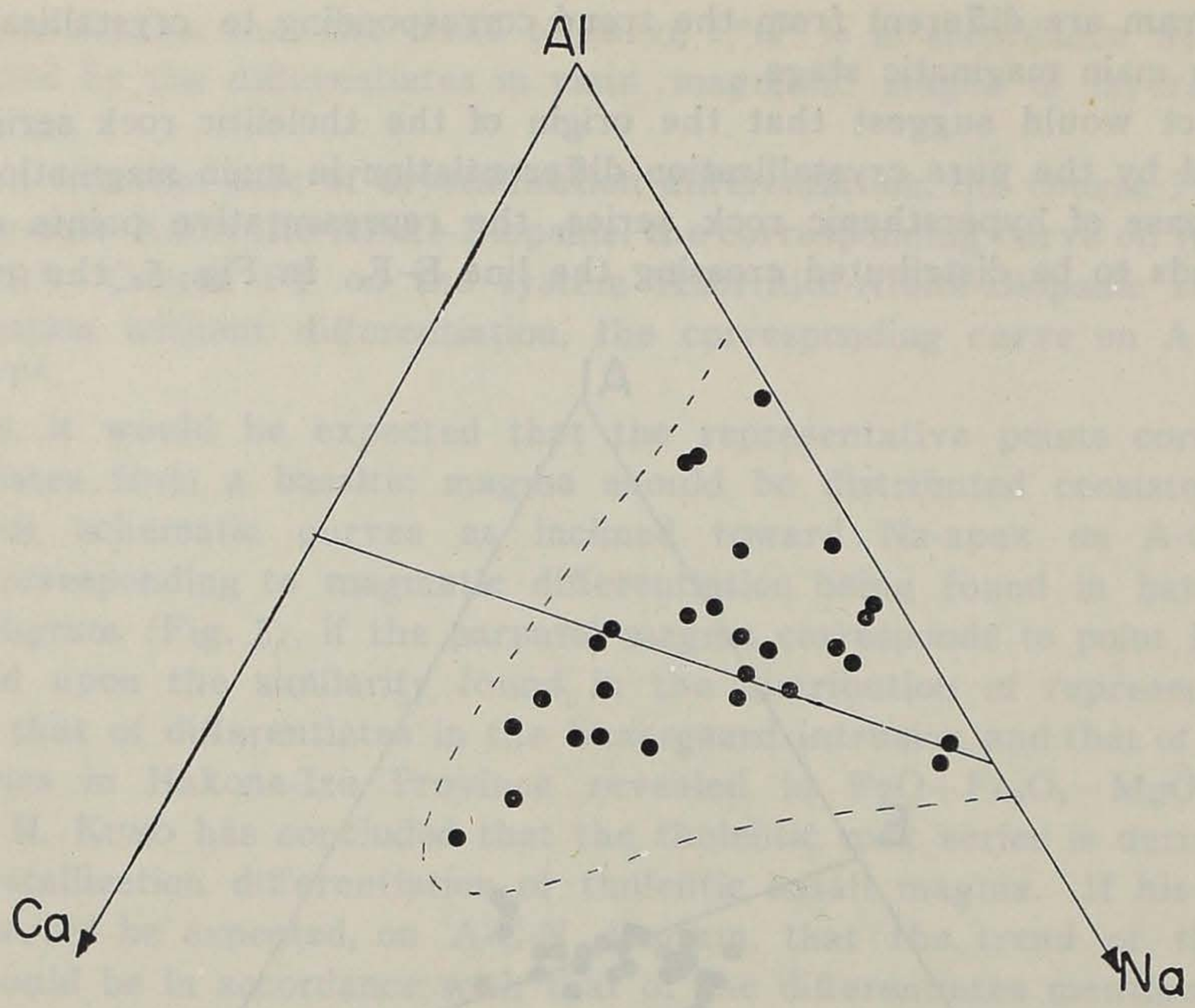
Fig. 5 A-C-N ratios of hypersthenic rock series.

tive points of hypersthenic rock series in the Nasu Volcanic zone and Fuji Volcanic zone are shown.

That the representative points are found on Al side of the line E-F means that these hypersthenic rock series are characterized by higher content of Al not included in feldspars (mainly 6 fold Al?) and/or higher content of potash feldspar in comparison with tholeiitic rock series.

The representative points corresponding to alkaline affinity (those of the Circum Japan Sea Petrograghic Province) are shown in Fig. 6. In this case, the distribution of representatives are nearly limited to bounded area. The features of A-C-N ratios of hypersthenic and alkaline rock series revealed in Fig. 5 &Fig. 6 would mean that the origin of these rock series is not explained by the concept of magmatic differentiation also.

A definite rock series would mean the rock suit formed in a definite genetic system. However, if the discussions above mentioned are allowable, this genetic system not seems necessarily to mean a definite magma itself, in which magmatic



Alkalaline rock series.

(Circum Japan Sea Petrographic Province)

Fig. 6. A-C-N ratios of Alkaline rock series

differentiation and assimilation take place.

On the other hand, it is noticed that, as a whole, the petrographic characters in volcanic rocks depend upon their geologic setting.

We know that, in a definite orogenic belt, the characters of magmatisms are distinguished among those of geosyncilinal stage, orogenic stage and post orogenic stage. Moreover, the fact that, roughly speaking, the rock series are distinguished to each other between those of continental areas and those of oceanic areas is noted. These facts would suggest that as the genetic system, we should choose definite geologic province in cosidering the genesis of definite rock suit. In this case, the writer considers the possibility that definite rock series indicates some definite conditions, under which magmas of similar petrographic character are generated.

3. Neogene volcanic activities in the Southwest Japan.

In order to examine the possibility suggested in section 2, in the following sections, the writer intends to show how the petrological characters of rock suit depend upon their tectogenetical situations in the case of Neogene volcanisms in Honshu, Japan, with special references to those in the Southwest Japan.

Honshu island is subdivided into the two geologic provinces: the Northeast Japan and the Southwest Japan by the so called Fossa Magna or more particularly by the Itoigawa-Shizuoka tectonic line.

3.1 The characteristics of the basement of Neogene formations in the Southwest Japan —— especially on the "Cretaceous acid volcanics" ——

In tectogenetical sense, the Southwest Japan is different from the Northeast Japan in many respects. In the case of Neogene, it is easily seen that the sediments and the volcanics are thickly developed in the Northeast Japan compared to those in the Southwest Japan, in which the basement of Neogene crops out in vast areas.

Generally speaking, it is noticed that, the Neogene crustal movement of the Northeast Japan is stronger than that of the Southwest Japan, being characterized by folding and faulting. On the other hand, that of the Southwest Japan is mainlyc haracterized by gentle warping.

From the data of gravity anomary and seismology (TAMAKI 1961), it is pointed out that sialic crust in the Southwest Japan is thicker than that in the Northeast Japan. Thus, the crust of Southwest Japan would have rather cratonic character comparing to that of the Northeast Japan. The differences in Neogene above cited would be due to such differences of the nature of the crust between the two.

As later pointed out, the cratonic character of the crust in the Southwest Japan seems to be refrected in the petrographic characters in Neogene volcanic rocks. Moreover, we can recognize such refrections in pre-tertiary volcanics also.

In this connection, the so called "Cretaceous acid volcanics", the distribution of which covers vast areas in the Southwest Japan, would have important meaning. The so called "Cretaceous acid volcanics" in the Southwest Japan consists of such formations as the Futomiyama group in Hokuriku, the Yadagawa in North Tajima, the Arima group in Harima, the Takada rhyolite and the Sakugi volcanics in Chugoku mountainland and the Nohi acid volcanics in Mino-Hida mountainland. These formations are unconformably overlain by the Miocene sediments in about all areas. Clastic sediments are rare or only locally intercalated in these formations, being characterized by gentle structure in general.

It is noticeable that the considerablly large part of these volcanics are composed of welded tuffs indicating the eruptions on land.

It is remarkable that these rocks have common characters: mineralogically all of them have potash feldspar and petrochemically they are characterized by rather high ratio of K_2O/Na_2O. As represented in Fig. 7, Al–Ca–Na ratios seem to suggest their semi-alkaline character.

In the outer side of the Southwest Japan, during Jurassic to early Neogene, took place the intensive tectogenesis, which is represented by the Shimanto zone. This zone comprizes geosynclinal thick sediments and metamorphic rocks. On the other hand, in the inner side, such "orogenic" movement is not known during Jurassic to Palaeogene period.

This would mean that the crust of the inner side was in cratonic condition during this duration.

The distribution of "Cretaceous acid volcanics" is limited to the inner side of the Southwest Japan. As far as known to the writer, in North Tajima district, dykes equivalent to acid volcanics above cited are commonly intruded in the direction of N–S trend ····· oblique to the Honshu arc, which is parallel to the Shi-

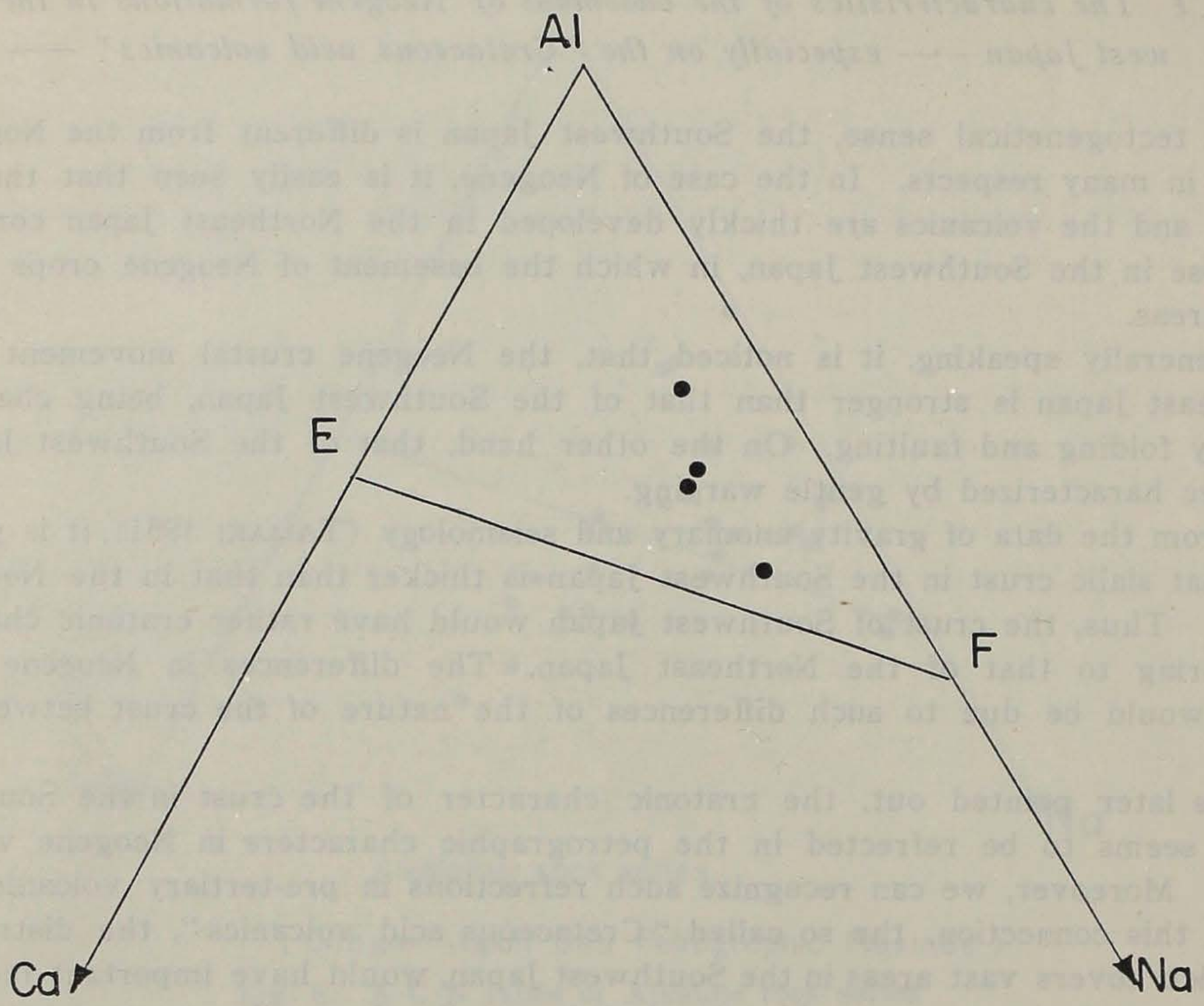


Fig. 7. A-C-N ratios of "Cretaceous" acid Volcanics.

manto zone.

It is suggestive that acid volcanics of late Cretaceous to Palaeogene period are known to have vast distribution in Sikhote Alin and its adjacent areas. These acid volcanics seem to show remarkable similarity in petrographic characters with

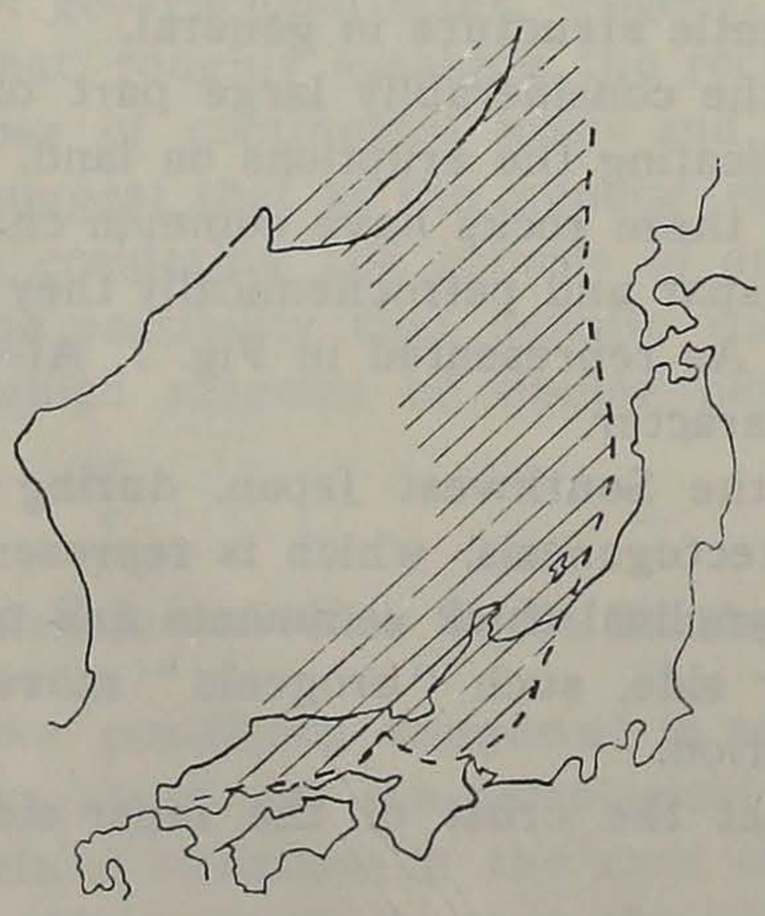


Fig. 8.

that of the Southwest Japan. In this case, it is noticeable fact that these acid volcanics are not known in the Northeast Japan except that found in Sado island and in Oga Peninsula.

Then, the hatched area in Fig. 8 would be infered to be covered by enormous acid volcanics probably of late Cretaceous to Palaeogene period. This hatched area would correspond to thick sialic massif.

It is noted that this area is roughly in agreement with the Cenozoic petrographic Province of alkaline rock series.

As later refered to, the volcanisms during Miocene are different to each other in petrographical character between those of the Southwest Japan and those of the Northeast Japan.

3.2 Neogene geologic provinces in the Southwest Japan.

The Neogene volcanic series in the Southwest Japan are discriminated depending upon geologic provinces and tectogenetical stages. So the Neogene geologic provinces must be defined at first. The geologic provinces in this article are established after the definition given by the Cenozoic Research Group of the Southwest Japan, to which the writer belongs as one of the members. They are discriminated as follows. (Fig. 9)

1. the Saikai province.
2. the Southwest Japan in narrow sense. { the Nankai province; the Inside province { the Setouchi province; the San'in-Hokuriku province }

In these provinces, the Saikai province is remarkably different from the others in the following points: 1) prevalence of non-marine sediments containing coal seams in palaeogene and Neogene formations and 2) plateau basalt of olivine basaltic composition in Pliocene to Pleistocene (?).

These characteristics may suggest that the crust of this province is characterized by continental elements more strongly than that of the other provinces. But the detailed data are not yet available, the considerations of igneous activities in this province are not made here.

The Inside and the Nankai provinces are different to each other in the features of volcanic activities. However, it seems to be possible to relate their activities in tectogenetical stand point (table 6).

The writer intends to synthesize Neogen volcanic activities in the Southwest Japan in connection with that of the San'in-Hokuriku province.

3.3 The volcanic series in the San'in-Hokuriku province.

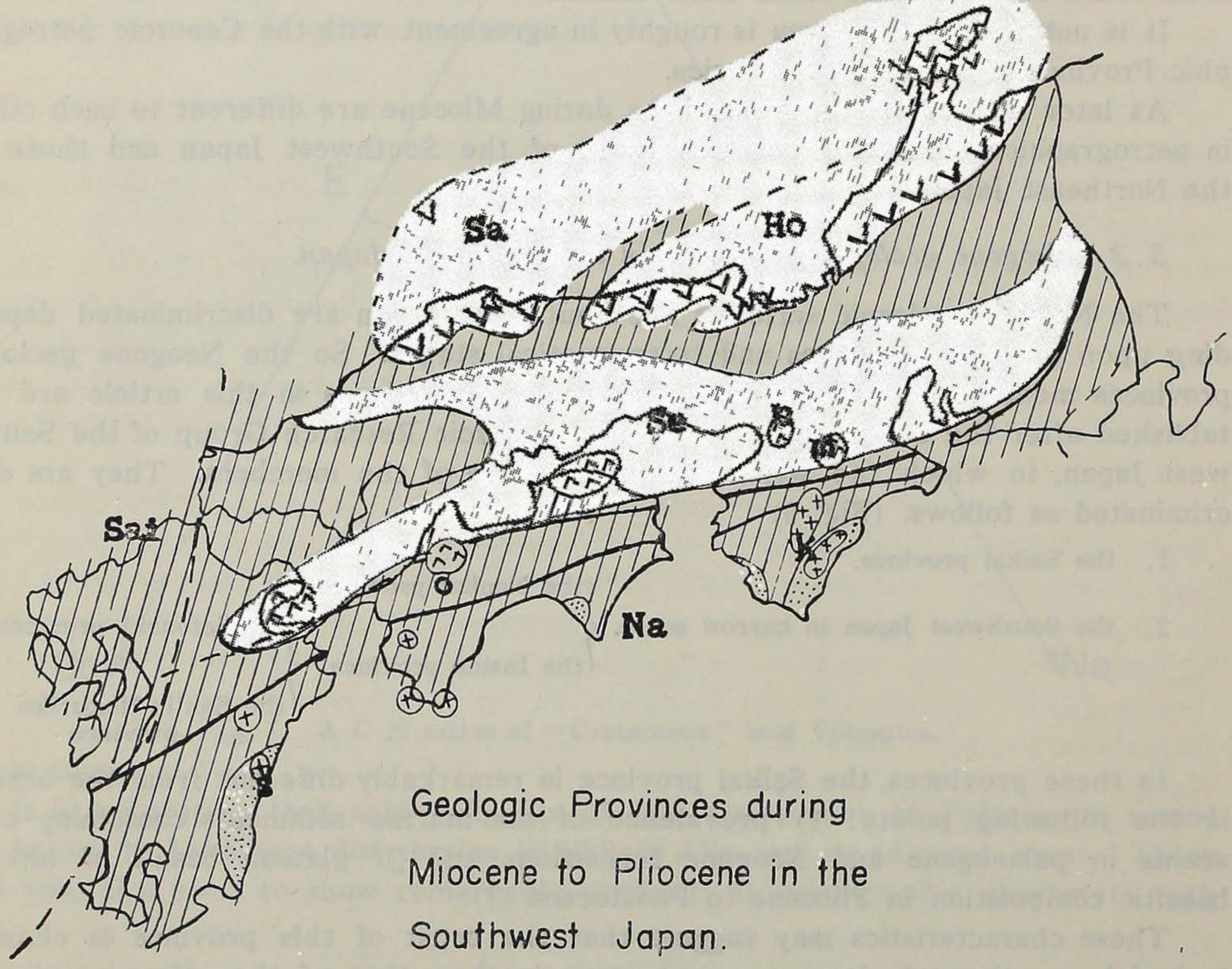
In comparison with the Setouchi and the Nankai provinces, this province is characterized by the enormous volcanics. As a whole, the sedimentary basins are situated extending along the Honshu arc.

The geohistory of this province from middle Miocene to Pliocene is divided into four stages: initial, middle, later and post respectively.

In each stage, the volcanic activities with definite petrographic characters took place.

a) The volcanics in the initial stage.

The initial stage in the San'in-Hokuriku province begum with the deposition of such nepton series as the Nirehara formation in the central part of the Hokuriku province (Toyama basin), the Takayanagi formation in the western margine of the Hokuriku province.



Geologic Provinces during Miocene to Pliocene in the Southwest Japan.

I·V volcanic series in San'in-Hokuriku Province.

Sa: San'in Province
Ho: Hokuriku Province
Se: Setouchi Province
Sai: Saikai Province
Na: Nankai Province

volcanic series in Setouchi Province

acid rocks in Nankai Province

Sediments in Nankai Province,

s: Suzuoyama volcanics
K: Kumano acid rocks
m: Muroo volcanics
n: Nijo volcanics

Fig. 9. Neogene geologic Provinces in Southwest Japan.

These nepton series are mainly composed of arcose sandstone and conglomerate. In the Nirehara formation, sometimes molluscan fossils are found, indicating marine condition. But, in the Takayanagi formation, fossil remains except plant fossils are not found, probably indicating non marine condition. In the San'-in province also, the clastic sediments correlated with the formations above cited are believed to be non marine.

It is noted that these nepton series seem to have been deposited in local basins scaterly distributed in this province.

Commonly these series are covered conformably by such formations as the Iwaine formation in the central part of the Hokuriku province, the Yoka formation in the western margine of the Hokuriku province and the Hata-Kimitani formations in the San'in province. These formations are mainly composed of basic lavas and equivalent pyroclasts intercalated sometimes by clastic sediments, in which marine molluscan fossils are often found in the case of the central part of the Hokuriku province.

From these facts, it is infered that the initial stage of this province begun with the subsidence of the crust resulted in the birth probably of lakes zonally arranged along the Honshu arc in the San'in province and in the western margine of the Hokuriku province, and that this subsidence brought about the invasion of sea water in the central part of the Hokuriku province. This depressional movement would have been succeeded by the violent volcanic activies, larger part of which became to take place under submarine condition, as the subsidence was advancing. The volcanics in the initial stage are composed of basic lavas and the equivalent pyroclasts. Petrographically, these rocks are characterized mainly by tholeiitic rock series, judging from the distributions of representatives on AFM diagram (Fig. 10).

Calc-alkalic rocks are found also in North Tajima district, which is shown by the presence of groundmass-hypersthene and AFM ratios.

However, in general, such cases are subordinate in the volcanic rocks of the initial stage.

Table 1. Chemical compositions of the rocks suit in the initial stage.

	1.	2.	3.	4.	5.	6.
SiO_2	50.32	52.85	55.09	55.35	59.48	59.83
Al_2O_3	17.22	15.60	18.14	17.81	15.99	17.37
Fe_2O_3	4.32	4.43	6.59	5.58	3.15	2.98
FeO	5.44	4.02	2.38	3.57	2.40	3.71
MnO	0.37	1.03	1.21	0.53	1.91	0.63
MgO	4.55	3.22	2.89	2.33	1.47	1.62
CaO	9.40	11.08	7.33	7.81	2.56	7.33
Na_2O	4.52	2.24	2.66	3.48	6.35	4.20
K_2O	0.94	1.84	1.14	0.85	2.44	1.72
TiO_2	0.58	1.05	0.65	0.43	2.19	0.21
P_2O_5	0.49	—	—	0.18	0.46	0.35
^+H_2O	2.42	0.97	1.92	0.69	1.70	0.53
H_2O	(ig. los.)	1.50	0.58	1.45	(ig. los.)	0.47
Total	100.57	99.83	100.58	100.06	100.10	100.95

No. 1-6 represent the basic rocks of the Hata F. (M. Mukae 1958)

Table 1 The chemical composition of the rock suit in the initial stage.

	7.	8.	9.	10.	11.	12.
SiO_2	52.33	53.59	57.64	54.12	59.84	59.75
Al_2O_3	19.40	17.07	15.00	18.69	15.65	16.11
Fe_2O_3	3.10	2.22	2.12	3.17	2.28	3.52
FeO	7.53	7.49	6.63	3.58	5.29	3.42
MnO	n.d.	0.19	0.15	n.d.	0.18	0.09
MgO	2.41	3.48	2.56	3.81	1.91	1.91
CaO	8.17	7.62	5.92	8.58	5.38	5.35
Na_2O	2.88	4.18	4.73	2.29	4.50	4.81
K_2O	0.47	0.87	1.07	2.48	1.74	2.31
TiO_2	n.d.	1.32	2.01	n.d.	1.19	1.52
P_2O_2	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
^+H_2O	3.14	1.15	0.90	2.77	1.48	0.65
H_2O	(ig.los.)	0.68	0.88	(ig.los.)	0.38	1.03
Total	99.71	99.86	99.65	99.48	99.82	100.47

No. 7-12 : The basic rocks of the Iwaine F,, central part of the Hokuriku province (T. Matsumoto 1958)

Table 1 The chemical composition of the rock suit in the initial stage.

	13	14	15	16	17	18	19	20
SiO_2	55.76	59.40	53.46	48.16	50.61	54.85	52.12	56.18
Al_2O_3	18.98	15.36	17.11	16.97	17.00	16.60	13.10	13.47
Fe_2O_3	4.03	1.75	8.10	11.41	11.58	9.61	11.54	8.92
FeO	2.03	3.08						
MnO	0.11	0.11	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
MgO	2.33	2.79	5.40	6.17	3.91	2.92	7.01	7.37
CaO	7.40	6.83	8.26	10.04	7.48	6.27	8.25	6.44
Na_2O	2.73	2.11	3.77	4.77	4.80	4.91	2.70	3.23
K_2O	1.45	0.83	0.63	0.38	0.67	1.40	1.05	1.26
TiO	0.83	0.59	0.69	1.20	1.33	0.88	0.49	0.04
P_2O_5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
^+H_2O	2.08	5.79	3.38	2.05	1.94	2.10	4.90	4.85
^-H_2O	1.56	1.34	(ig.los)	〃	〃	〃	〃	〃
Total	99.55	100.11	100.11	100.15	99.32	99.44	101.16	99.76

No.13-20 : The basic rocks of the Yoka F. (T. Matsumoto 1961)

Although the representative points on AFM diagram are plloted in the pigeonitic field after H. Kuno, it is noted that, generally speaking, these volcanics are considerably high in Na_2O content. Some rock species are similar to spilite or mugearite in chemical composition. In Al_2O_3–Na_2O+K_2O diagram (proposed by H. KUNO), the representative points are plotted on tholeiite field, field of high alumina basalt and field of alkaline affinity (after H. KUNO) separately (Fig. 11).

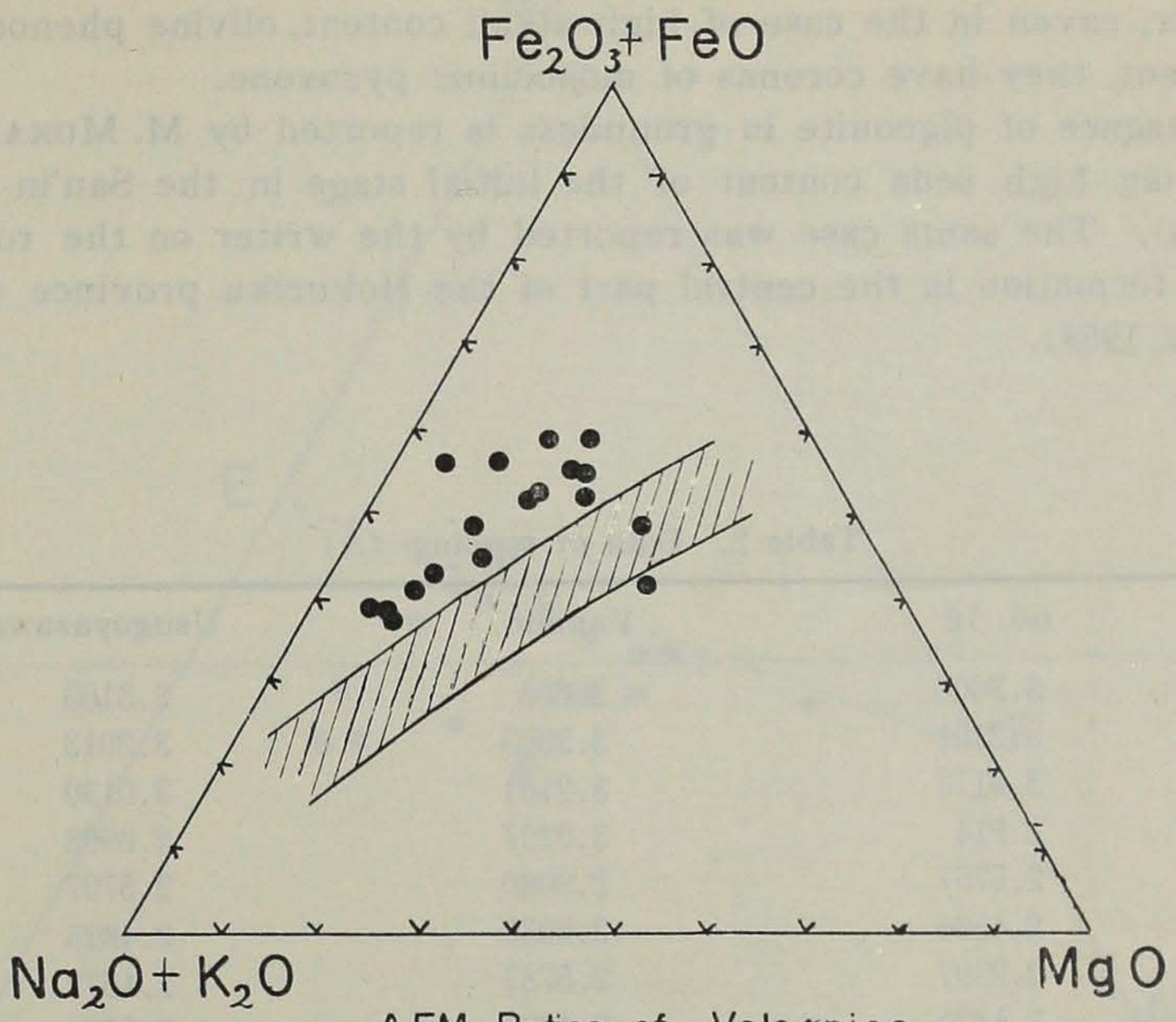


Fig. 10. AFM Ratios of Volcanics in the initial stage.

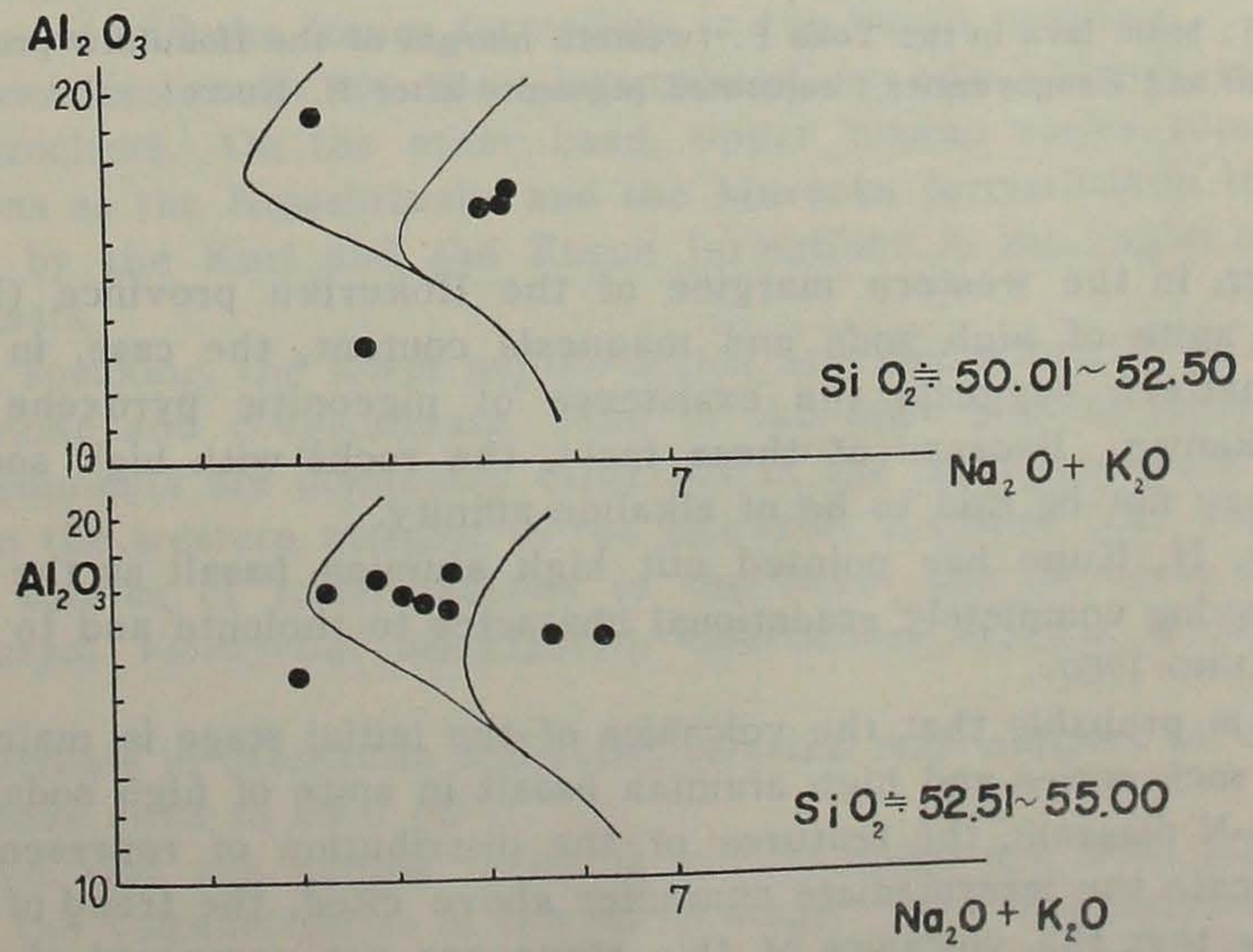


Fig. 11. $Al_2O_3 - Na_2O + K_2O$ diagram of volcanics in the initial stage.

However, eaven in the case of high alkali content, olivine phenocryst are rare, and, if present, they have coronas of monoclinic pyroxene.

The presence of pigeonite in groundass is reported by M. MUKAE on the rock species having high soda content of the initial stage in the San'in province. (M. MUKAE 1958). The same case was reported by the writer on the rock species of the IWAINE formation in the central part of the Hokuriku province (T. MATSUMOTO, N. IKEBE 1958).

Table 2. Data of spacing (Å)

no. 16	Yumoto	Usugoyazawa
3.3606	3.603	3.3165
3.2101	3.3305	3.2013
3.0173	3.2101	3.0130
2.914	3.0207	2.8998
2.5757	2.9080	2.5707
2.4596	2.9035	2.4825
2.2307	2.5783	2.4672
2.1425	2.4882	2.572
2.0473	2.4591	
	2.2315	
	2.2230	
	2.1457	
	2.1167	
	2.0449	
	2.0410	

No. 16 : basic lava in the Yoka F. (western margin of the Hokuliku province)
Yumoto and Usugoyazawa : separated pigeonite after H. Kuno

Moreover, in the western margine of the Hokuriku province (North Tajima district), in spite of high soda and magnesia content, the case, in which X-ray diffraction pattern suggests the exsistence of pigeonitic pyroxene as shown in table 2, is known. Because of these facts, the rocks with high soda content in this stage may not be said to be of alkaline affinity.

Recently, H. Kuno has pointed out high alumina basalt as the intermediate rock type having completely gradational character to tholeiite and to alkali olivine basalt (H. KUNO 1960).

Then it is probable that the volcanics of the initial stage is mainly composed of tholeiitic rock series and high alumina basalt in spite of high soda content.

On A-C-N diagram, the features of the distribution of representative points seem to indicate the intermediate character above cited, the trend of the distributionindicating that the volcanics of this stage are not composed of differentiates from common parental magma, if the discussions in the previous section is allowable (Fig. 12).

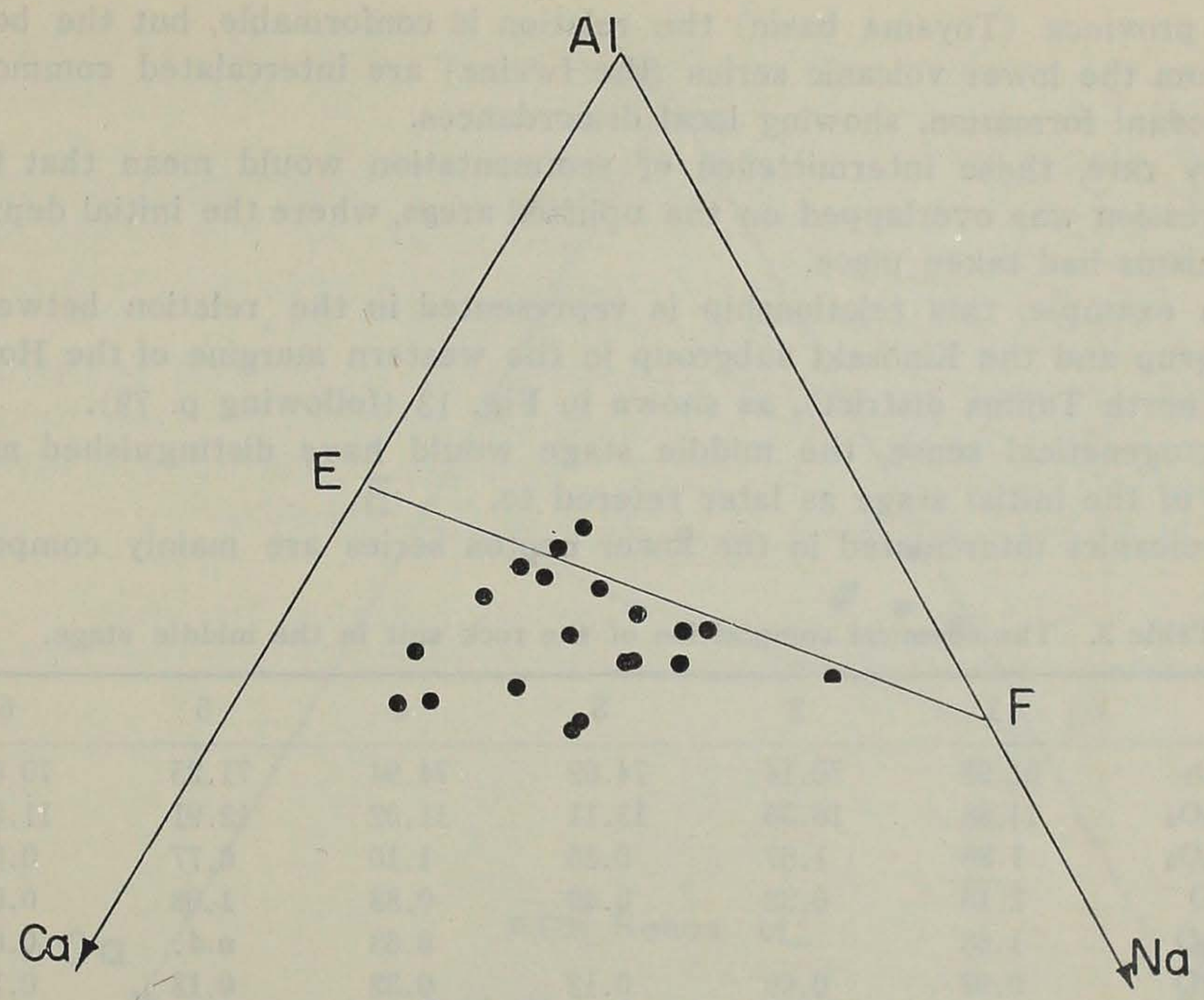


Fig. 12. A-N-C ratios of Volcanics in initial Stage.

b) The volcanics in the middle stage.

The nepton series in the middle stage are divided into two subdivisions: the lower series and upper series. The lower series are represented by such formations as the Kurosedani and the Toyooka formations in the Hokuriku province and by the Kawai and the Koura formations in the San'in province.

These lower formations are often intercalated by acid volcanic mass and the equivalent pyroclasts. On the other hand, upper nepton series represented by such formations as the Higashibesho and the Muraoka formations in the Hokuriku province and by the Kuri and the Furue formations in the San'in province are rare in pyroclasts.

Generally speaking, the lower nepton series are characteristic of coarse sediments: sandstone and conglomerate. And in the lowe part of these series, the non marine sediments are dominated especially in the San'in province (the Kawai, Koura) and in the western margine of the Hokuriku province (the Toyooka).

Common species of fossil remains in the lower part of these series are as follows: *Vicarya, Vicaryella, Miogypsina, Operculina, Myrica, Liquidamba and Metasequoia.*

The similarities in lithofacies and fossil remains may support to correlate the formations above cited to each other.

It is noted that the nepton series in middle stage are often disconformably underlain by the volcanic series in the initial stage. Such discoformable relations are seen in the San'in province and in the western margine of the Hokuriku province (North Tajima district). In the central and in the eastern part of the

Hokuriku province (Toyama basin) the relation is conformable, but the boulders derived from the lower volcanic series (the Iwaine) are intercalated commonly in the Kurosedani formation, showing local discordances.

At any rate, these intermittence of sedimentation would mean that the revised depression was overlapped on the uplifted areas, where the initial depression and volcanisms had taken place.

As an example, this relationship is represented in the relation between the Yabu subgrup and the Kinosaki subgroup in the western margine of the Hokuriku province (north Tajima district), as shown in Fig. 13 (following p. 79).

In tectogenetical sense, the middle stage would have distinguished meaning from that of the initial stage as later refered to.

The volcanics intercalated in the lower nepton series are mainly composed of

Table 3. The chemical composition of the rock suit in the middle stage.

	1	2	3	4	5	6
SiO_2	64.98	70.14	74.69	74.94	71.25	70.60
Al_2O_3	14.88	16.36	13.11	11.02	12.91	11.50
Fe_2O_3	1.88	1.67	0.85	1.10	0.77	0.59
FeO	2.15	0.32	0.49	0.83	1.08	0.62
MnO	1.68	—	—	0.63	n.d.	0.04
MgO	0.93	0.09	0.12	0.32	0.13	0.10
CaO	5.42	1.36	0.06	2.20	1.84	1.00
Na_2O	4.21	6.14	4.01	5.76	3.24	4.10
K_2O	0.94	1.05	4.12	1.11	3.86	1.71
TiO_2	1.83	—	—	0.84	n.d.	0.09
P_2O_5	0.45	—	—	0.19	n.d.	n.d.
^+H_2O					4.48	7.49
^-H_2O	0.58 (ig.los.)	2.79 (〃)	1.95 (〃)	0.83 (〃)	0.40	2.30
Total	99.93	99.82	99.40	99.77	100.24	100.20

No. 1-4 : The acid rocks in the Kawai F. San in province (M. MUKAE 1958)
No. 5-6 : 〃 in the Toyooka F., Hokuriku province (T. MATSUMOTO 1958,1961)

acid to intermediate rock species: soda rhyolite, pitchstone and hornblende bearing dacite, all of which belong to hypersthenic rock series after H. KUNO. The writer has pointed out that the representative points of calk-alkalic rock series tend to be distributed in the field of Al side by the line EF on A-C-N diagram. As revealed in Fin. 14, this tendency is recognized in this case.

If the middle stage has the different tectogenetical meaning from the initial stage, then such volcanics can hardly be explained to be derived from the common parental magma with the initial stage by pure differentiation or by assimilation. This seems to be revealed by the trend of representatives on A-C-N diagram, which is clearly different from that of tholeiitic rock series. Moreover, this trend suggests that these rocks of the middle stage can not be the products of magmatic differentiation from a definite basaltic magma generated in the middle stage.

c) The volcanics of the later stage. (late Miocene to early Pliocene.)

The nepton series in this stage are represented by such formations as the

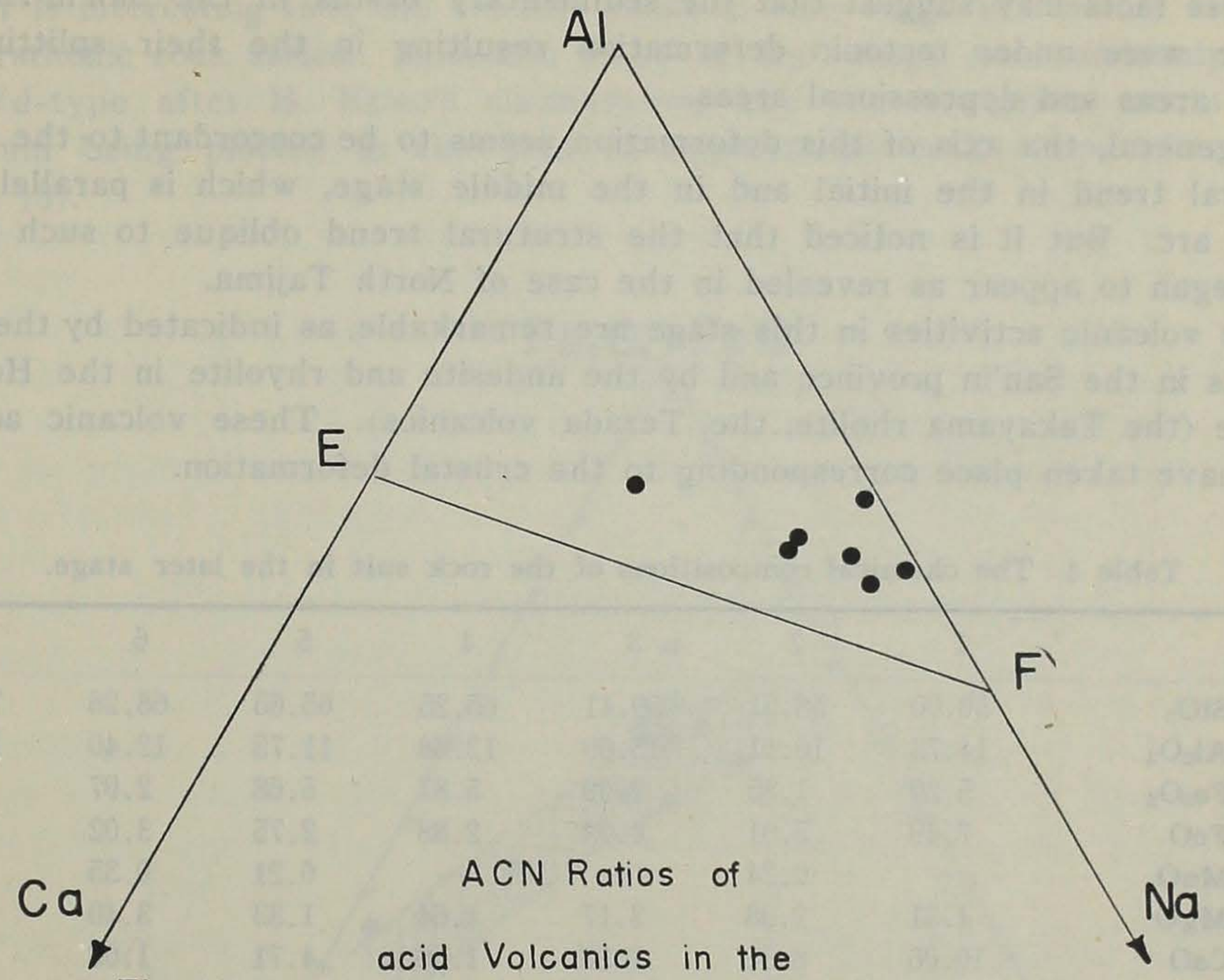


Fig. 14.

Otokawa formation and the Teragi proup in the Hokuriku province, the Omori formation and the Fujina formations in the San'in province. As already mentioned, the sedimentary formations in the middle stage have similar feature in lithological sense through the San'in-Hokuriku province.

On the contrary, the nepton series in this stage are variable remarkably in thickness and in lithofacies. The uncoformable or disconformable relations to the lower formations representing the middle stage are common.

As an example, the structural relation between the Teragi group and the lower formations (the Kinosaki, the Yabu) in North Tajima district is illustrated in Fig. 13.

It is remarkable that the Teragi group is situated discordantly to the main structural trend of the lower formations, and the intrusive masses ecuivalent to the volcanics intercalated in the Teragi group are always intruded along the fissures of N–S trend, which is oblique to the main structural direction in the initial and in the middle stages.

In the central part of the Hokuriku province, the local disconformity at the base of the Otokawa formation, and the uplift of Noto Peninsulr in this stage are known.

In the San'in province, in its southern area, the distinct disconformity is known at the base of the Omori formation. On the other hand, in its northern area, the formations of middle stage (the Koura) and that of the later stage (the Furue) are in conformable relation.

These facts may suggest that the sedimentary basins in the San'in-Hokuriku province were under tectonic deformation resulting in the their splitting into uplifted areas and depressional areas.

In general, the axis of this deformation seems to be concordant to the general structural trend in the initial and in the middle stage, which is parallel to the Honshu arc. But it is noticed that the strutural trend oblique to such general trend began to appear as revealed in the case of North Tajima.

The volcanic activities in this stage are remarkable, as indicated by the Omori volcanics in the San'in province and by the andesite and rhyolite in the Hokuriku province (the Takayama rholite, the Terada volcanics). These volcanic activities would have taken place corresponding to the crustal deformation.

Table 4 The chemical compositions of the rock suit in the later stage.

	1	2	3	4	5	6	7
SiO_2	50.00	58.51	59.41	65.25	65.65	68.26	71.32
Al_2O_3	14.73	16.11	15.69	12.88	11.75	12.40	14.66
Fe_2O_3	5.20	1.85	2.99	5.87	5.68	2.97	2.37
FeO	7.49	5.01	4.72	2.88	2.75	3.02	0.12
MnO	—	0.24	—	—	0.21	0.35	—
MgO	4.31	2.98	3.17	4.64	1.33	3.40	0.12
CaO	10.06	8.51	7.50	1.56	4.71	1.03	0.73
Na_2O	1.71	1.94	2.06	2.46	3.10	2.93	6.04
K_2O	2.02	1.75	0.93	1.91	1.60	2.27	1.08
TiO_2	0.41	0.77	0.94	0.59	1.05	1.30	—
P_2O_5	—	—	—	—	—	—	—
^+H_2O	0.70	0.29	0.81	0.56	0.71	0.88	3.28
^-H_2O	2.53	1.49	1.03	0.82	1.19	0.57	
Total	99.16	99.45	99.25	99.42	99.73	99.38	99.72

No. 1-7: Andesite, rhyolite in the Omori F, San' in Province (M. Mukae 1958)

Table 4. The chemical compositions of the rock suit in the later stage.

	8	9	10	11	12	18
SiO_2	53.38	70.60	49.05	50.84	53.09	63.74
Al_2O_3	19.92	11.50	18.43	18.77	16.50	16.68
Fe_2O_3	0.88	0.59	4.58	10.92	8.72	4.29
FeO	5.55	0.62	4.92			
MnO	n.d.	0.04	n.d.	n.d.	n.d.	n.d.
MgO	4.90	0.10	7.02	4.46	4.77	1.89
CaO	8.66	1.00	7.71	6.14	10.73	5.07
Na_2O	2.16	4.10	3.09	4.84	2.52	5.17
K_2O	2.61	1.71	0.41	0.51	0.47	1.11
TiO_2	n.d.	0.09	1.00	1.38	0.66	—
P_2O_5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
^+H_2O	1.88	7.45	4.37	1.63	2.57	1.34
^-H_2O	(ig.los.)	2.30	(ig.loss)			
Total	99.94	100.20	100.91	99.31	100.02	99.82

No. 8-13 : Andesite & rhyolite in the Hokuriku province. (T. Matsumoto 1961)

It is interesting that the volcanic rocks in this stage are mainly composed of hypersthenic rock series. Andesitic rocks of this stage are commonly classified as Vd-type after H. KUNO'S classification, the representative points on AFM diagram being plotted in the field of hypersthenic rock series after H. KUNO (Fig. 15).

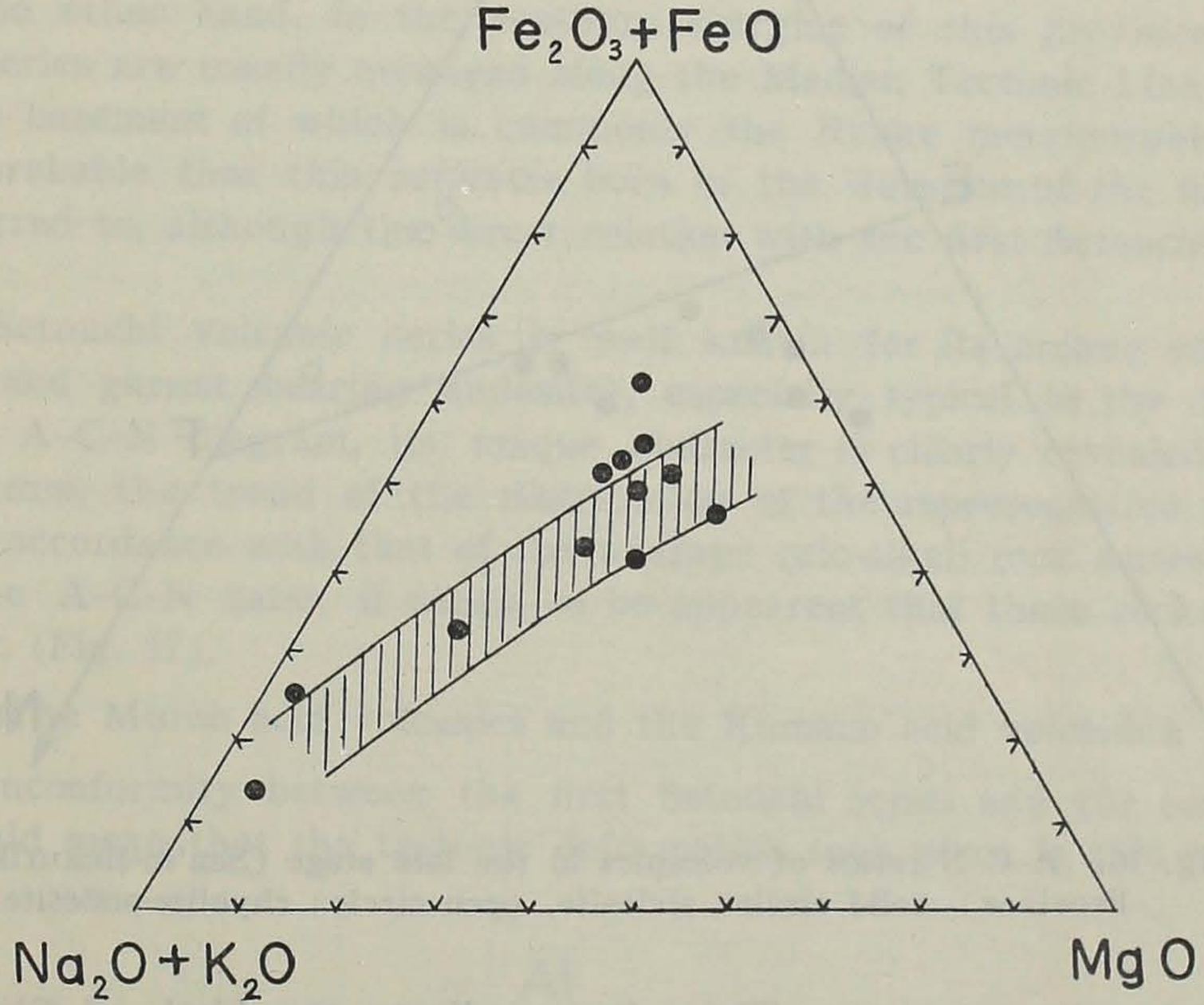


Fig. 15. AFM ratios of volcanics in the later stage [San'in-Hokuriku-Province]

On A-C-N diagram, the representative points are distributed crossing the line E-F, this trend being distinguished from those of the initial and middle stages. It is noted that acid rocks in this stage are higher in Al/Ca+Na than those in the middle stage, as revealed on A-C-N diagram (Fig. 16).

d) The volcanics in the post stage. (late Pliocene to Recent)

The nepton series in this stage are mainly represented by the Himi group in the Hokuriku province and the Matsue formation in the San'in province. These strata are characterized by the "Omma-Manganjian Molluscan fauna". In this stage, the structural patterns, which have oblique trend to the Honshu arc, became to prevail.

This is contrasted with the fact that the structural patterns in the preceeding stages are generally concordant with the Honshu arc.

The volcanic activities in this stage are characterized by alkaline affiinity, especially in the San'in province, as indicated by olivine basalt intercalated in the upper horizon of the Matsue formation, alkaline rocks in Oki island and

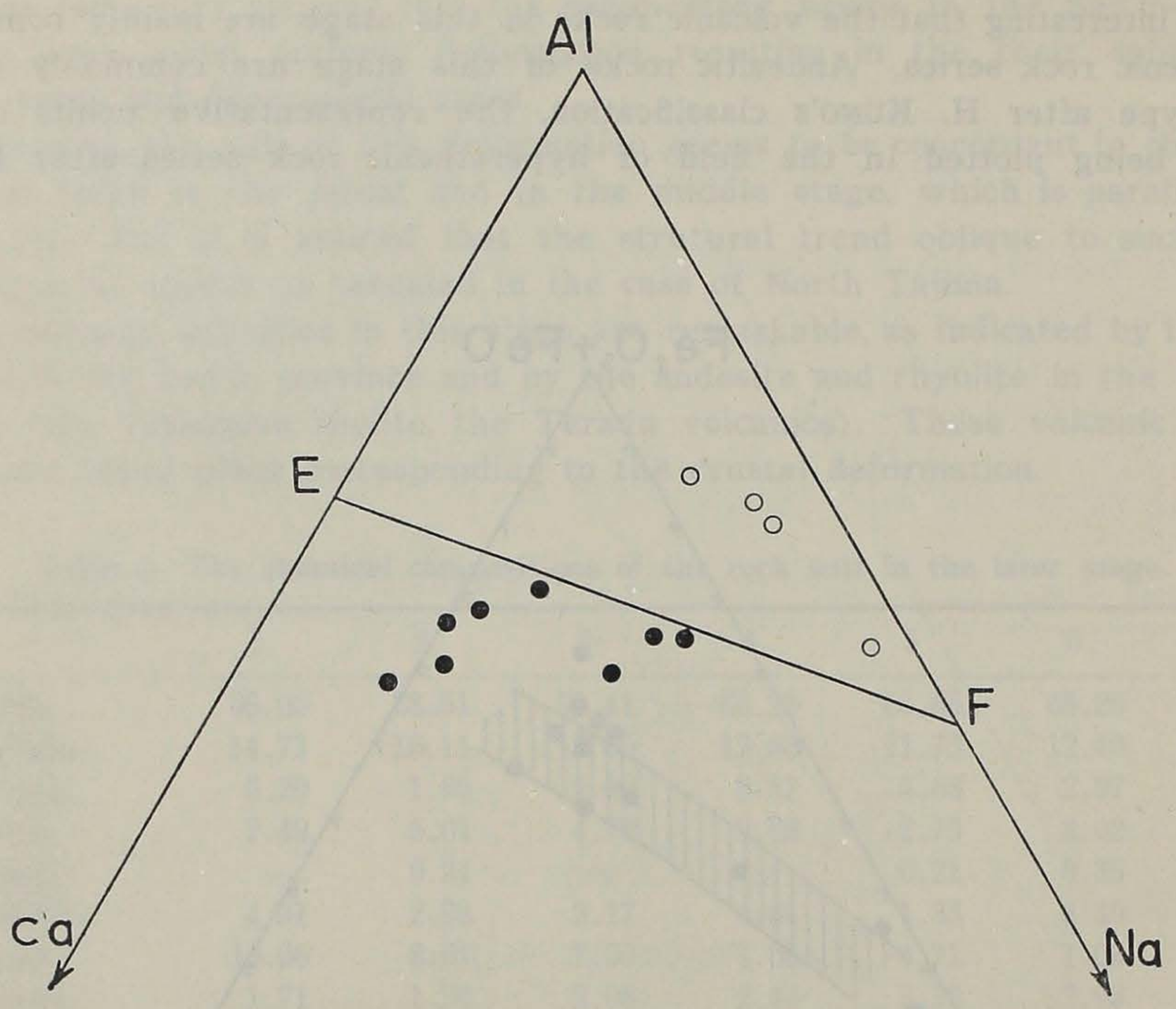


Fig. 16. A-C-N ratios of volcanics in the late stage [San'in-Hokuriku Province] solid circle : andesite, open circle : rhyolite-andesite.

olivine basalt in adjacent areas. These facts indicate the birth of Circum Japan Sea Petrographic province in the post stage.

In the Hokuriku province also, olivine dorelite probably of Pliocene is reported by S. ISHIDA in Noto Peninsula. Further, the volcanics of alkaline affinity probably of Pleistocene-Recent are often found in the western margine of the Hokuriku province (Kannabe olivine basalt, Genbudo olivine basalt and the equivacones) as well as in the San'in province.

That the volcanic activitities of alkaline affinity are inherited from Pliocene to Recent would suggest that the similar tectonic condition prevailed in this duration. Its tectogenetical meaning will be considered in the next section.

3.4 Note on the volcanic activities in the Setouchi and the Nankai provinces.

a) Sanukitoid and related rocks.

The Setouchi province is characterized by its quasi-cratonic character of the basement. The Cenozoic nepton series in this province are deposited in narrow sedimentary basins scatterly distributed.

The nepton series are divided into that of Miocene series (the first Setouchi series) and that of Pliocene-Pleistocene series (the second Setouchi series). The two nepton series are in unconformable relation. In this case, the first Setouchi series are rich in fossil remains common to those found in the lower nepton series in the middle stage of the San'in-Hokuriku province : *Vicarya, Vicaryella, Miogyp-*

sina etc. Thus, roughly to say, the first Setouchi series may have formed in the duration of the earlier time of the middle stage. It is noticed that the first Setouchi series are often intercalated by the pyroclastic sediments. In general, these pyroclasts are derived from rhyolitic or dacitic eruptions.

It is most provable that in the Setuchi province also, the acid or intermediate volcanic activities took place simultaneously with those in the San'in-Hokuriku province.

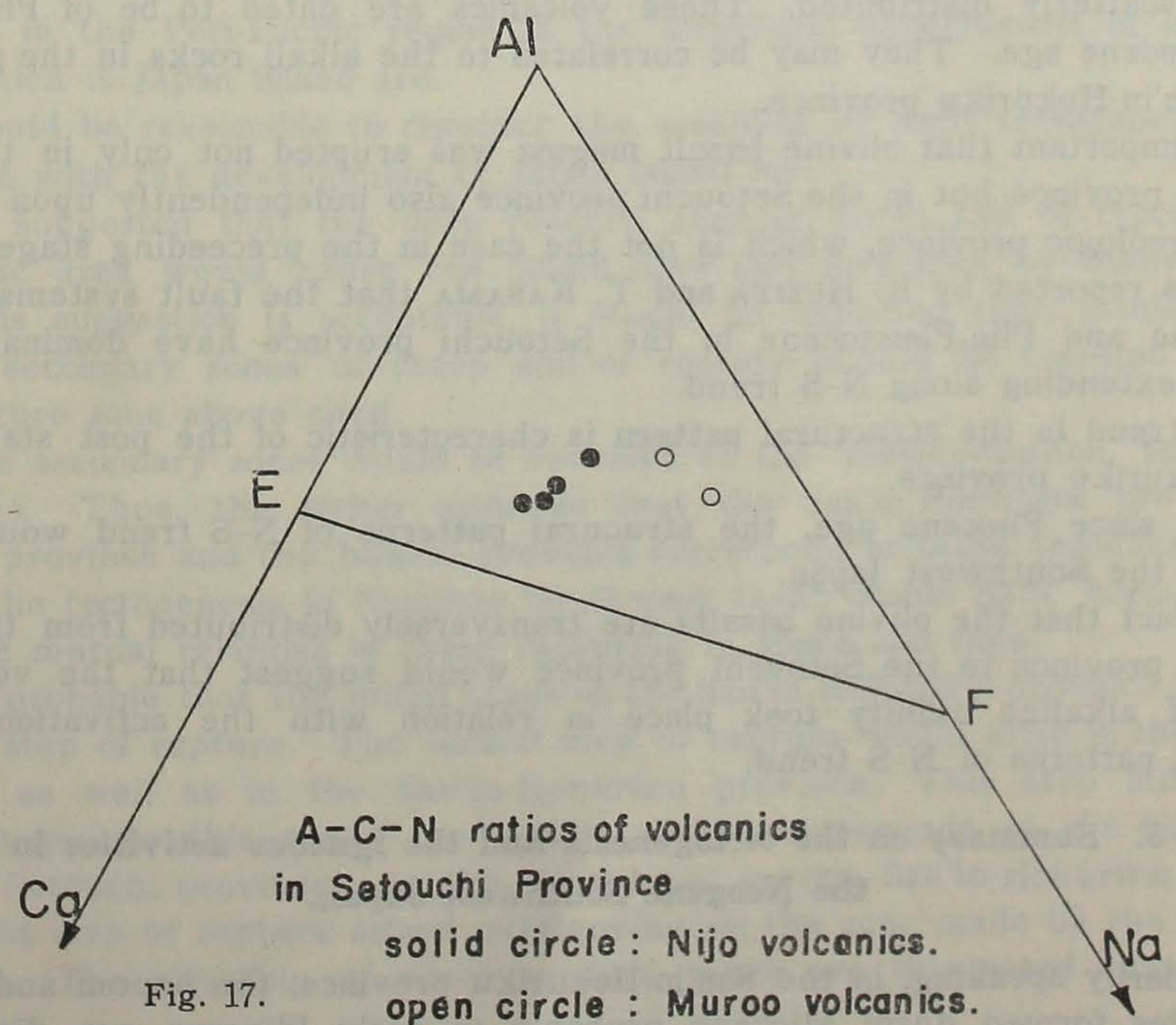
On the other hand, in the southern margine of this province, the Setouchi volcanic series are zonally arranged along the Median Tectonic Line of Southwest Japan, the basement of which is commonly the Ryoke metamorphic complex. It may be probable that this series is born in the duration of the middle stage as later referred to, although the direct relation with the first Setouchi series is not known.

The Setouchi volcanic series is well known for its unique rock association (sanukite and garnet bearing andesite), especially typical in the Nijyo volcanic area. On A-C-N diagram, its unique character is clearly revealed, although on AFM diagram, the trend of the distribution of the representative points is completely in accordance with that of the average calc-alkali rock series.

From the A-C-N ratio, it seems to be appearent that these rocks are high in Al content (Fig. 17).

b) The Muroo acid volcanics and the Kumano acid volcanics.

The unconformity between the first Setouchi series and the second Setouchi series would mean that the tectonic deformation took place in this interruption of



A-C-N ratios of volcanics
in Setouchi Province
solid circle : Nijo volcanics.
open circle : Muroo volcanics.

Fig. 17.

sedimentation.

The second Setouchi series may be correlated with the nepton series and volcanic series of the post stage in the San'in-Hokuriku province.

The Muroo volcanics is mainly constructed by welded tuff of enormuos amount, which suggests that its eruption took place on land. Stratigraphically, this volcanics is unconformably underlain by the first Setouchi series and overlain unconformably by second Setouchi series.

Petrographically, it is composed of anorthoclase bearing rhyolite, the A-C-N ratio of which is different from that of the sanukitoid and its related rocks. As already pointed out, in the acid rocks of the later stage in the San'in-Hokuriku province, potash rhyolite is often found (Takayama rhyolite etc.). It is suggestive that the petrochemical characters of the Muroo volcanics are similar to that of the Takayama rhyolite as revealed on A–C–N diagam (Fig. 17).

Then, the writer infers that the Muroo volcanics was erupted in correspondence with the volcanic activities of the later stage in the San'in-Hokuriku province.

In the Nankai province, the Miocene sediments are intruded by the Kumano acid rocks, which include abundant welded tuffs. These acid rocks are characterized by the presence of anorthoclase, being similar with the Muroo volcanics in petrographical sense.

From these facts, the writer believes that the Kumano acid rocks are correlated to the Muroo volcanics in the Setouchi province.

c) Note on the volcanic rocks of alkaline affinity.

In the Setouchi province, volcanic cones of dykes of olivine basaltic composition are scatterly distributed. These volcanics are dated to be of Pliocence or Plio-Pleistocene age. They may be correlated to the alkali rocks in the post stage of the San'in-Hokuriku province.

It is important that olivine basalt magma was erupted not only in the San'in-Hokuriku province but in the Setouchi province also independently upon the difference in geologic province, which is not the case in the preceeding stages.

It was reported by K. HUZITA and T. KASAMA that the fault systems activated in Pliocene and Plio-Pleistocene in the Setouchi province have dominantly such strike as extending along N–S trend.

This trend in the structural pattern is charecteristic of the post stage in the San'in-Hokuriku province.

Thus, since Pliocene age, the strucural patterns of N–S trend would prevail wholly in the Southwest Japan.

The fact that the olivine basalts are transversely distributed from the San'in-Hokuriku province to the Setouchi province would suggest that the volcanic activities of alkaline affinity took place in relation with the activations of the structural patterns of N–S trend.

5. Summary on the tectogenesis and the igneous activities in the Neogene Southwest Japan.

Summarily speaking, in the San'in-Hokuriku province, the nepton and the volcanic series formed durig Miocene probably to early Pliocene are divided into

three series: first, second and third series. The first series mainly consists of volcanic materials (the Iwaine, the Yoka and the Hata), indicating the initial stage. The writer calls this series as the first volcanic series.

The second series mainly consists of clastic sediments interposed by acid to intermediate volcanics in its lower part, indicating the middle stage. The writer calls this acid volcanics as the second volcanic series. The third series consists of volcanics of calk-alkaline affinity and clastic sediments, indicating the later stage. This volcanics will be called as the third volanic series.

In this section, tectogetical meaning of each stage will be suggested. It is important in tectogenetical sense that the first series and the second series are separated to each other by disconformity or discordance. In this intermittence, the areas occupied by the first volcanic series must have been eroded.

The thickness of the second series does not correspond to the thickness of the underlying first series. Eaven when the first volcanic series is thickly developed, the overlying second series is not necessarily developed thickly as in the case of the western margine of the Hokuri province. In this case, the second series is represented by the second volcanic series only, although the thickness of the first volcanic series nearly overcome 500m.

Moreover, it is noted that, in general, the maximum thickness of the second serie rarely overcomes 700m±.

These facts may suggest the that second series represents another basin-formation distinguished from that represented by the first series, and the San'in-Horuriku province can hardly be explained by the concept of eugeosyncline. The absense of metamorphic zone in this province may support this suggestion.

In this connection, it is noted the, during Cenozoic era, the most fundamental processes in the Peri-Pacific region is the structural development of island arcs, one of which is Japan island arc.

It would be reasonable to cnosider the meaning of each tectogenetical stage in relation with the development of Japan island arc.

It is suggested that the deep reached zone of creep and or rapture in the Peri-Pacific area would cause the island arcs and fore-deep by many authors.

If this suggestion is acceptable, it would be expected that, inside of island arc, the secondary zones of creep and/or rapture should be resulted from the main rapture zone above cited.

These secondary zones would be revealed as the basin-formation, faulting and volcanisms. Thus, the writer assumes that the San'in-Hokuriku province, the Setouchi province and the Nankai province correspond to these secondary rapture zones. The tectogenesis in Neogene Southwest Japan would have been determined by the mutual relations of these rapturing in space and time.

It is probable that the initial stage in the San'in-Hokuriku province represents the first step of rapture. The second step of rapture would arize in the Setouchi province as well as in the San'in-Hokuriku province. This step indicates the middle stage. In this sense, the middle stage corresponds to the birth of the Neogene Setouchi province. At the same time, in the San'in-Hokuriku province, the second step of rapture arized overlapping on the zone made by the first step-rapturing. The situation of these rapture zones are illustrated tentatively by Fig. 18.

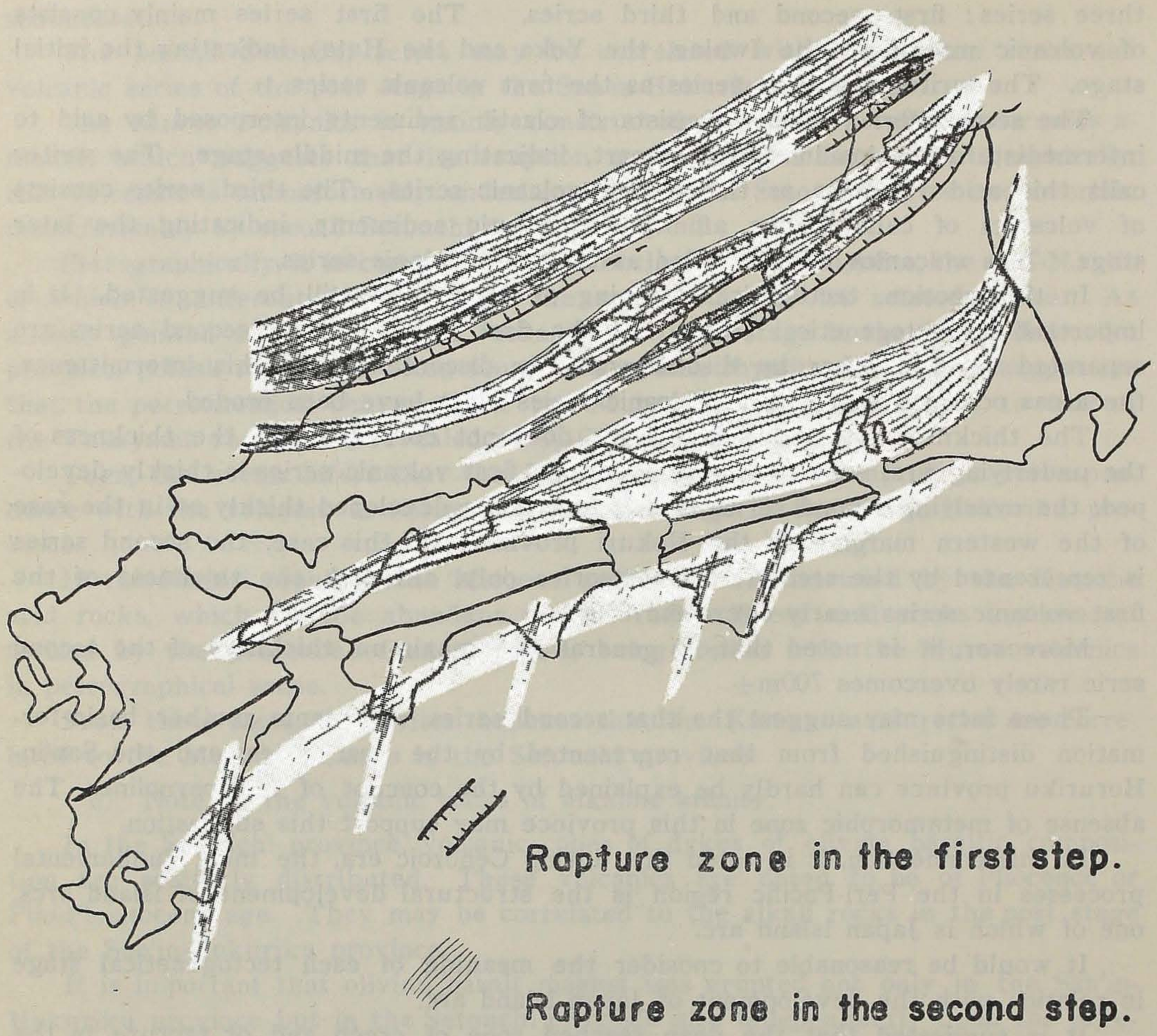


Fig. 18 Schematized figure showing rapture zones in Southwest Japan.

In the San'in-Hokuriku province, the second volcanic series may be erupted through the fracture systems in the second step, and the eruptions may be expected in the Setouchi and in the Nankai provinces as well.

In the Nankai province, the Osuzuyama acid rocks in the Miyazaki group would correspond to this eruption. From the same reasoning, and by the fact that sanukitoid and its related rocks are unconformably overlain by the acid rocks correlated with the Muroo volcanics, the writer has infered that the Setouchi volcanic series should be erupted in the duration of the middle stage.

In the duration of the initial and the middle stage, the structural patterns in the Southwest Japan are concordant with the trend of the Hoshu arc.

The structural patterns in the later stage is generally concordant with the trend of the Honshu arc also. Neverthless, it is recalled for that the trend oblique to the Honshu arc is found in the western margine of the Hokuriku province, as has been cited.

Thus, it may be probable that, in this stage, the two rapture systems, in

which the one is concordant with the trend of the Honshu arc and the other is with that of the Ryukyu arc, wre coupled. In relation to this suggestion, acid rocks in the Nankai province is noted.

According to A. MIZUNO, although the structural patterns in the Nankai province is essentially in agreement with the trend of the Honshu arc, the axes of warping parallel to the Ryukyu arc are coupled with the essential trend above cited. According to him, this coupling has taken place already in early Miocene.

On the other hand, the igneous activities in the Nankai province are characterized by acid rocks (Osuzuyama acid rock in the mindle stage, the Kumano acid rocks in the later stage). In this case, it is noted that these acid rocks are associated with the plutonic phase.

Petrographically, these rocks are always high in Al/Na+Ca ratio. In the inside province, the activities of acid rocks, which are higher in Al/Na+Ca ratio, took place in the later stage, as have been cited. In the Inside province, the plutonic masses with such characteristics as above cited are found only in the later stage. The Omogo granitic mass in the Setouchi province is one of the case.

Thus it might be probable that the coupling of the two rapture systems favours the intrusion of these acid rocks.

The, post stage is distinguished from the preceeding stages in that the structural patterns oblique to the Honshu arc prevails in general. And this would mean that the tectonic movements along the Ryukyu arc became active in stead of those along the Honshu arc, and the secondary rapture systems resulted from these movements are revealed in the structural patterns oblique to the Honshu arc.

Olivine basalts would be erupted through these rapture systems.

It is natural that their distribution covers both the two provinces: the San'in-Hokuriku and the Setouchi. (Fig. 19)

In Plio-Pleistocene period, the eruptions of calk-alkali rocks took place in the Southwest Japan as shown by the Daisen volcanic series, the representatives of

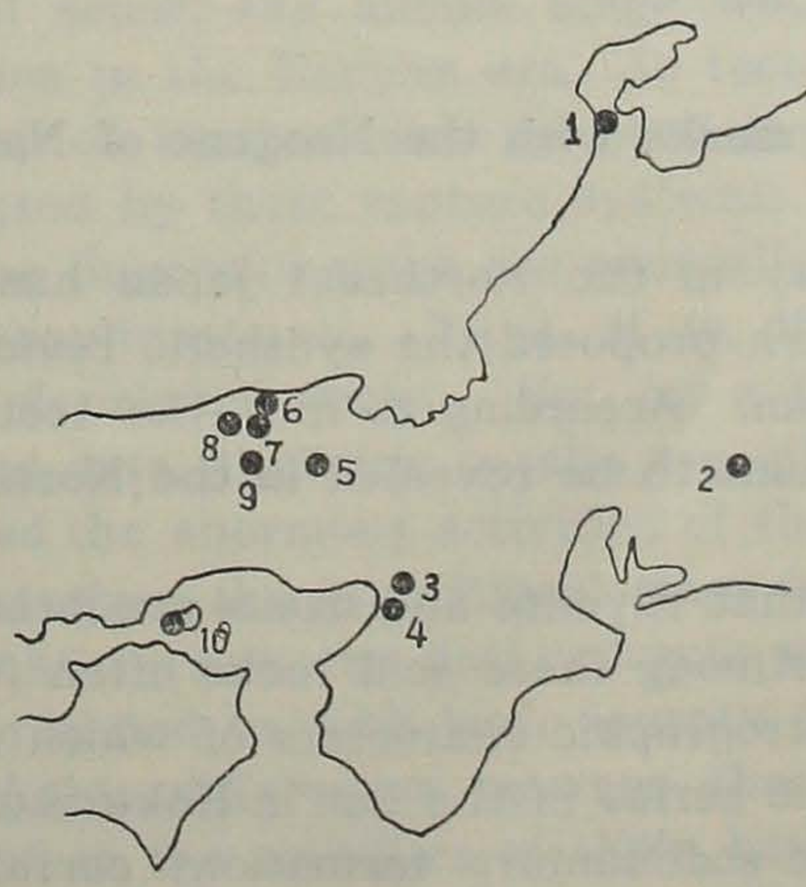


Fig. 19. **The Distribution of Olivine Basalt in the post stage**

which are found not only in the San'in-Hokuriku province but in the Setouchi province also.

This series seems to form ruled by the tectonic patterns paralled to the Ryukyu arc. But the detailed discussions are not refered to here. In table 5, the tectogenetical development and igneous activities in the Southwest Japan are synthesized.

Table 5. Synthesis of the Cenozoic Voloanic Series in Southwest Japan.

		Hokuriku-San' in province	Setouchi Province.	Nankai Province
Pleistcene		↑	↑	
Pliocene	post stage	olivine basalt, trachyte	olivine basalt	
late Miocene	later stage	3rd volcanic series (calc alcalic : andesite, potash rhyolite)	Muroo acid volcanics (potash rhyolite), Omogo acid rocks.	Kumano acid rocks.
middle Miocene	middle stage	2nd volcanic series (calc alkalic : soda rhyolite, hornblende andesite)	Setouchi volcanic series	
	initial stage	lst volcanic series (tholeiite, high alumina basalt)		
		Cretaceous acid rocks.		

6. Correlative remarks with the Neogene of Northeast Japan.

The Neogene geohistory in the Northeast Japan has been studied by many authors. Recently, Y. FUJITA proposed the synthetic review on the geohistory in the Neogene Northeast Japan. According to him, the tectogenetical stages found in the Southwest Japan seems to be revealed in the Northeast Japan also. Table 6 shows this relations.

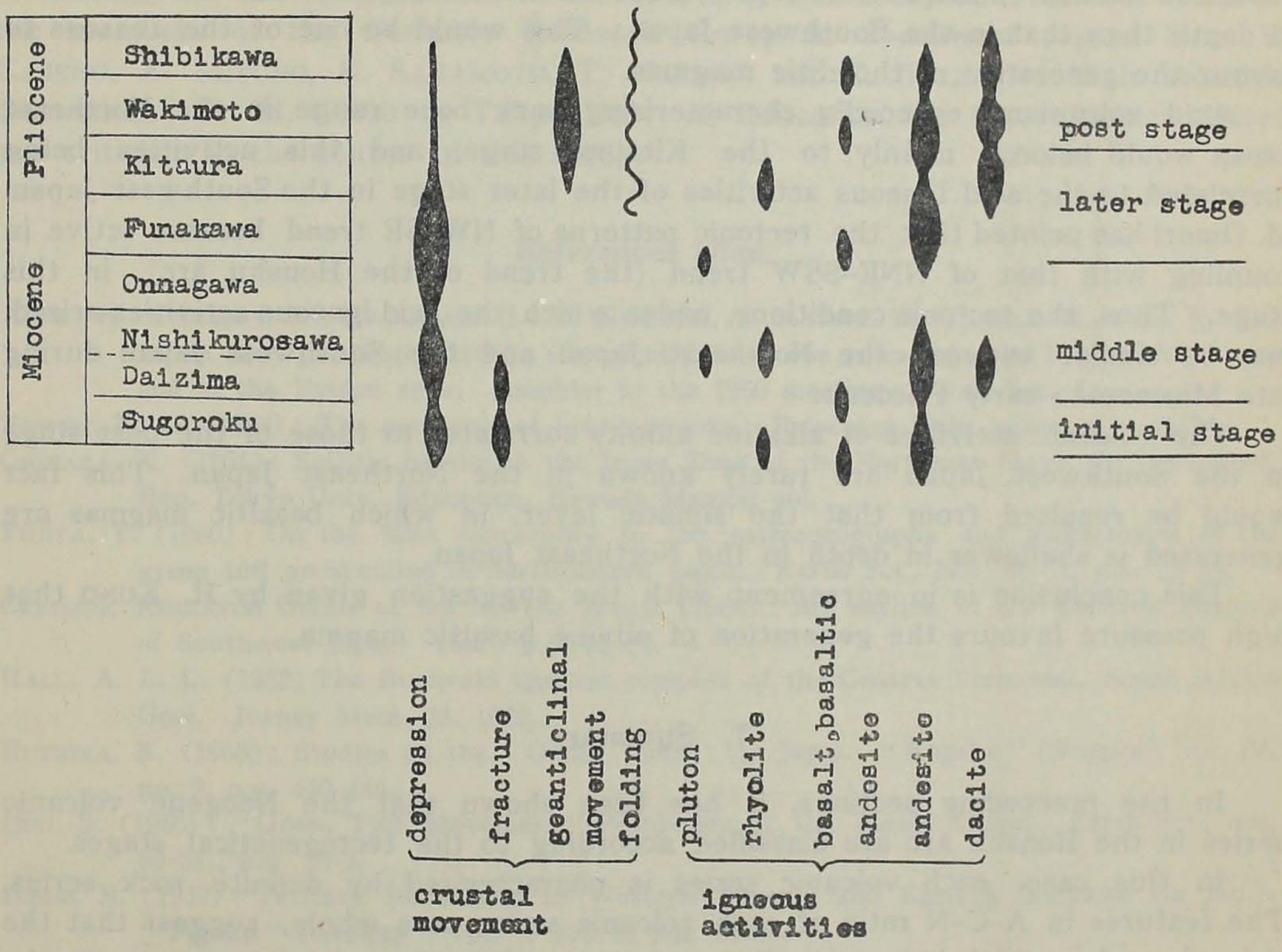
Especially, it is noted that rhyolite and dacite are intercalated in the Daijima-Nishikurosawa formation. Among these acid rocks often found are so-called plagioliparite and pitchstone, petrographic characters of which resemble to that of acid rocks in the second volcanic series in the San'in-Hokuriku province.

On the other hand, the sedimentary formations correlated with the Daijima-Nishikurogawa formation are known to be distributed widely in the Northeast Japan. These formations comprize common species of fossil remains: *Myogipsina Operculina, Vicarya, Vicaryella* and plant fossils of Daijima flora. These fossil remains are characteristic of the second series and the first Setouchi series in the

Table 6. Comparison of igneons activities and tectonic deformations between Northeast Japan and Sowthwest Japan.

Northeast Japan — Southwest Japan

(Synthesis after Y. Huzita simplified by the writer)



Southwest Japan also.

In palaeogeographical sense, the middle stage would represent the time of the maximum transgression in the Honshu arc. In tectogenetical sense, it is probable that the second step of rapture was revealed in the Northeast Japan also, and acid rocks were erupted by these rapture systems.

The basic rocks in the Sugoroku stage are generally suffered from secondary alterations (so called propylitizations). Thus, it is difficult to determine their petrographic characters of original rocks. But by a few available examples of chemical and mineralogical data, tholeiitic basalts are often found in this stage.

S. KONDA has reported the enormous activities of tholeiitic rock series (mainly intrusive masses) characterizes the transitional stage between the Daijima-Nishikurogawa and the Sugoroku. Thus, the first volcanic series in the San'in-Hokuriku province would be correlated to such basic igneous activities.

However, the remarkable differences between the Southwest Japan and the Northeast Japan are found in the activities of these basic rocks.

The first point of difference is that these basic rocks in the Northeast Japan are normal tholeiite. As has been cited, in the Southwest Japan, the first volcanic series is characterized by high alumina basalt and tholeiite rich in soda content.

The second point is that the basic igneous activities characterized by tholeiite are suceeded to the Funakawa stage correlated with the later stage in the Southwest Japan, which is not the case in the Southwest Japan. As has been discussed in section 3, the simatic layer in the Northeast Japan would be shallower in depth than that in the Southwest Japan. This would be one of the reasons to favour the generation of tholeiitic magmas.

Acid volcanisms especially characterizing back bone range in the Northeast Japan would belong mainly to the Kitaura stage, and this activities being correlated to the acid igneous activities of the later stage in the Southwest Japan. M. Omori has pointed that the tectonic patterns of NW–SE trend became active in coupling with that of NNE–SSW trend (the trend of the Honshu arc) in this stage. Thus, the tectonic conditions, under which the acid igneous activities arized, may be similar between the Northeast Japan and the Southwest Japan during late Miocene to early Pliocene.

The volcanic activities of alkaline affinity correlated to those of the post stage in the Southwest Japan are rarely known in the Northeast Japan. This fact would be resulted from that the simatic layer, in which basaltic magmas are generated is shallower in depth in the Northeast Japan.

This conclusion is in agreement with the suggestion given by H. KUNO that high pressure favours the generation of olivine basaltic magma.

7. Summary

In the preceeding sections, it has been shown that the Neogene volcanic series in the Honshu arc are classified according to the tectogenetical stages.

In this case, each volcanic series is characterized by definite rock series. The features in A–C–N ratio of each volcanic series, as a whole, suggest that the volcanic rocks, which belong to the same volcanic series, do not represent the differentiate from a common parental magma.

In this way, it may be concluded that the origin of the diversities in igneous rocks depends fundamentarily upon physical and chemical conditions, under which magmas are generated. The phenomena occurring in the course of solidification of a generated magma would play only secondary role for petrogenesis.

In other words, it seems most important, in order to make clear the petrogenesis, to know the processes of evolution of definite petrographic province, to which the rock suit in problem belongs.

This evolution would be determined essentially by the tectogenetical development in the deep crust and/or upper mantle.

The mechanism to generate magmas is one of the most difficult problems beyond the scope of this article.

However, the conditions, under which primary magmas are formed would be assumed by simple thermodynamical considerations, which will be described in another paper.

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References cited.

AOKI., K., ONUMMA, K., KADOWAKI, J., Y. KAWANO, Y. KATSUI, K. TANIDA, K. YAGI, K. KATSURA & H. HAYASHI (1960): Chemical data of the volcanic rocks in the Nasu zone and in the Tyokai zone. panphlet in the 1960 meeting of Vol. Soc. Jap.

BOWEN, N. L. (1928): The evolution of igneous rocks. Princeton Univ. press, p.p. 45-58.

CHIHARA, K. (1954): Spilitic basalts in the Inner Zone of the Northeast Japan. (in Jap.) Geol. Rep. Tokyo Univ. Education, Kawada Memoir-vol.

FUJITA, Y. (1960): On the laws concerning to the palaeogeography and geotectonics of the green tuff geosyncline in northeastern Japan. Earth Sci., Nos. 50-51, p.p. 22-35.

CENOZOIC RESEARCH GROUP of SOUTHWEST JAPAN (1960): An outline of the Cenozoic History of Southwest Japan. Ibid., p.p. 56-65.

HALL, A. L. L. (1932) The Bushveld igneous complex of the Central Transvaal, South Africa Geol. Jurney Mem. 28, 1932.

HUZIOKA, K. (1956): Studies on the "Green Tuffs" (in Jap.). "Kagaku" (Science), vol. 26, no. 9, p.p. 440-446.

IJIRI, S. (1960): "Green Tuff Movement"-Problemes of the Pacific Ocean. Earth Sci., nos. 50-51., p.p. 22-8.

IKEBE, N. (1949): Tertiary formations in Western Toyama and Eastern Ishikawa (in Jap.), "Tigaku" (Geology), vol. 1, nol. 1, p.p. 14-26.

——— (1950): Geology of the Takashozi mountains in Toyama (in Jap.), Nature and Society, no. 5-6, p.p. 12-16.

——— and et all (1951): Geological Studies in Toyama and Ishikawa Pref.-3, Mt. Hutakami area, "Tigaku" no. 3, p.p. 7-16.

——— (1954): Cenozoic Biochronology of Japan, Jour. Inst., Polytech., Osaka city Univ., Ser. G, vol. 1, no. 1, p.p. 73-86.

——— (1956): Cenozoic Geohistory of Japan, Proc. 8th Pac. Sci. Congr., vol. 2, pp. 446-456.

——— (1957): Cenozoic Sedimentary basing in Japan (in Jap.), Cenozoic Research, nos. 24-25, pp. 1-10.

ISHIKAWA, T. & Y. KATSUI (1959): Some considerations on the relation between the chemical character and geographical position of the volcanic zones in Japan, Jour. Fac. Sci. Hokkaido Univ., ser. 4, Geol., Miner., 10, pp. 163-182.

ITIHARA, M., G. ISHIO, A. MORISHITA, C. NAKAGAWA & K. TSUDA (1950): Geological Studies in Toyama and Ishikawa-2, Kanazawa, Isurugi and Hukumitu area (in Jap.). "Tigaku", no. 2, pp. 17-27.

KATO, I. (1955): Petrogenetic Considerations of the Green Tuffs found in the Yokote Basin in Akita and the Sinzyo Basin in Yamagata, Sci. Rep. Tohoku Univ., ser. 3, vol. 5, no. 1, pp. 1-94.

KAWADA. K., N. YAMADA, H. ISOMI, M. MURAYAMA & M. KATADA (1961): Geology of Japnese Central Alps and its Western Area (2) Nohi Rhyolites, Earth Sci., no. 54, pp. 20-39.

KENNEDY (1933) : Trends of differentiation in basaltic magmas, Am. Jour. Sci., 25, pp. 31-47.
KITAMURA, N. (1959) : Tertiary Orogenesis in Northeast Hoshu, Jap (in Jap.), Contrib., Inst. Geol. Palaeont., Tohoku Univ., no. 49, pp. 1-98.
———— (1960) : A cross Section through the Backbone Range in Northeast Honshu, Japan, Sci. Rep. Tohoku Univ., second ser. special vol., no. 4 (Hanzawa Memorial vol.)., vol 236-251.
KONDA, K (1960) : Geological and petrological studies on the Tertiary dolerite of the Dewa Hill northern Honshu, Bull. Yamagata Univ., vol. 5, pp. 55-87.
KUNO, H (1950) : Petrology of Hakone Volcano and adjacent areas, Japan, Bull. Geol. Soc. Am., vol. 61, pp. 957-1020.
———— (1953) : Unit cell-dimensions of clino-enstatite and pigeonite in relation to other common clino-pyroxene, Am. Jour. Sci., vol. 251.
———— (1954) : Volcanoes and volcanic rocks (in Jap.), Iwanami Co., Tokyo, pp. 187-189.
KUNO, H (1955) : Ion substitution in the Diopside-ferropigeonite series in clino-pyroxene, Am. Mim., vol. 40.
———— (1958) : Geology and petrology of O-shima Volcano (in Jap.), Bull. Volc., Soc. Japan, Ser. 2, 3., pp. 1-16.
———— (1959) : Origin of Cenozoic Petrographic provinces of Japan and surrounding areas, Bull. Volc., ser. 2, 20, pp. 37-76.
———— (1960) : High Alumina Basalt, Jour. Petro., vol. 1, no. 2, pp. 121-145.
KUSHIRO, I. (1959) : Preliminary note on Alkali-dolerite of Atumi district, northern Japan, Jap. Jour. Geol. Geogr., vol. 30, pp. 259-272.
MATSUMOTO, T (1957) : On A-C-N diagram (in Jap.), Earth Sci., no. 34, pp. 28-33.
———— & N. IKEBE (1958) : Volcanostratigraphical Studies on the Neogenic Hokuriku Prcvince, Jour. Inst. Polytech. Osaka city Univ., ser. G. 3, pp. 79-112.
———— & N. IKEBE (1958) : Some aspects on the Cenozoic geohistory in the Southwestern Japan, Earth Sci., vol. 137, pp. 17-28.
———— & K. WADATSUMI (1958) : Cenozoic Structural Development in Northern Tazima (2) (in Jap,), Jour. Geol., vol. 65, no. 762, pp. 117-127.
———— & ———— (1960) : Some Aspects of the Igneous Activities during the "Green Tuff Period" in Honshu Arc, Japan, Earth Sci. nos. 50-51, pp. 66-74.
MACDONALD, G. A. (1949) : Hawaiian Petrographic province, Bull. Geol. Soc. Am., 60, pp. 1541-1596.
MINATO, M., K. YAGI & M. HUNAHASHI (1956) : Geotectonic synthesis of the Green Tuff regions in Japan, Bull. Earthq. Res. Inst., vol. 34, pt. 3, pp. 237-265.
MIZUNO, A. (1957) : Neogene geohistory in the Pacific side of Southwest Japan-Neogen Sedimentary provinces in Japan and their developments (3), Cenozoic Research, nos. 24-25, pp. 28-41.
MORIMOTO, R., K. HUZITA & T. KASAMA (1957) : Cenozoic volcanism in Southwestern Japan, Bull. Eartq. Res. Inst., vol. 35, partl, pp. 35-45.
MUKAE, M. (1958) : Volcanostratigraphical Study on the Miocene Volcanism in the Shimane Prefecture, Japan, Jour. Sci. Hiroshima Univ. ser. C, vol. 2, no. 2, pp. 129-171.
OMORI, M. (1958) : A Brief Note on the Tectogenesis of the Tertiary System ni the Northeastern Honshu, Japan, Sic. Rep. Tokyo Edu. Univ. special vol. (Fujimoto Memorial volume), pp. 145-153.
POLDERVAART, A. & W.E. ELSTON (1954) : The calc-alkaline Series and the trend of Fractional Crystallization of basaltic Magna. Jour. Geol., vel. 62, no. 2, pp. 150-162.
TAMAKI, I. (1954) : The crustal structure of Japan derived from observed travel time curves of shallow earthquakes (in Jap.), Zisin, ser.2 , vol. 7, pp.1-7.
TAMAKI, I. (1961) : Seismicity in Relation to the Crust Structure, with Special Reference to Japanese Area, Mem. Osaka Inst. Tech. Ser. A : vol. 7, No. 2, pp. 1-95.
TSUYA, H. (1937) : On the Huzi Volcanic Zone, Bull. Earthq. Inst. Tokyo, vol. 15, pp. 215-357.

TILLEY, C. (1950) : Some Aspects of magmatic evolution, Q.J.G.S. vol. civ, partl, no. 421, pp. 37-62.

UMGROVE, J.H.F. (1947) : The pulse of the earth, 2nd Ed.

YAMASHITA, N. (1960) : Alpine Orogeny in Japan and problems of the Green Tuff Age, Earth Sci. nos. 50-51, pp. 9-21.

YODER, H. S. & C. E. TILLEY (1957) : Basaltic magmas, Annual Rep. Director Geoph. Lab. for 1956-7, pp. 156-161.

YOSHIDA, H. (1961) : The Late Mesozoic Igneous Activities in the Middle Chugoku Province, Geol. Rep. Hiroshima Univ., no. 8, pp. 1-39.

WAGER, L. R. & W. A. DEER (1939) : Geological investigations in East Greenland, III, The petrology of the Skaergaard intrusion, Kangerdlungssrak, East Greenland, Med. om Grnland, 105, no. 4.

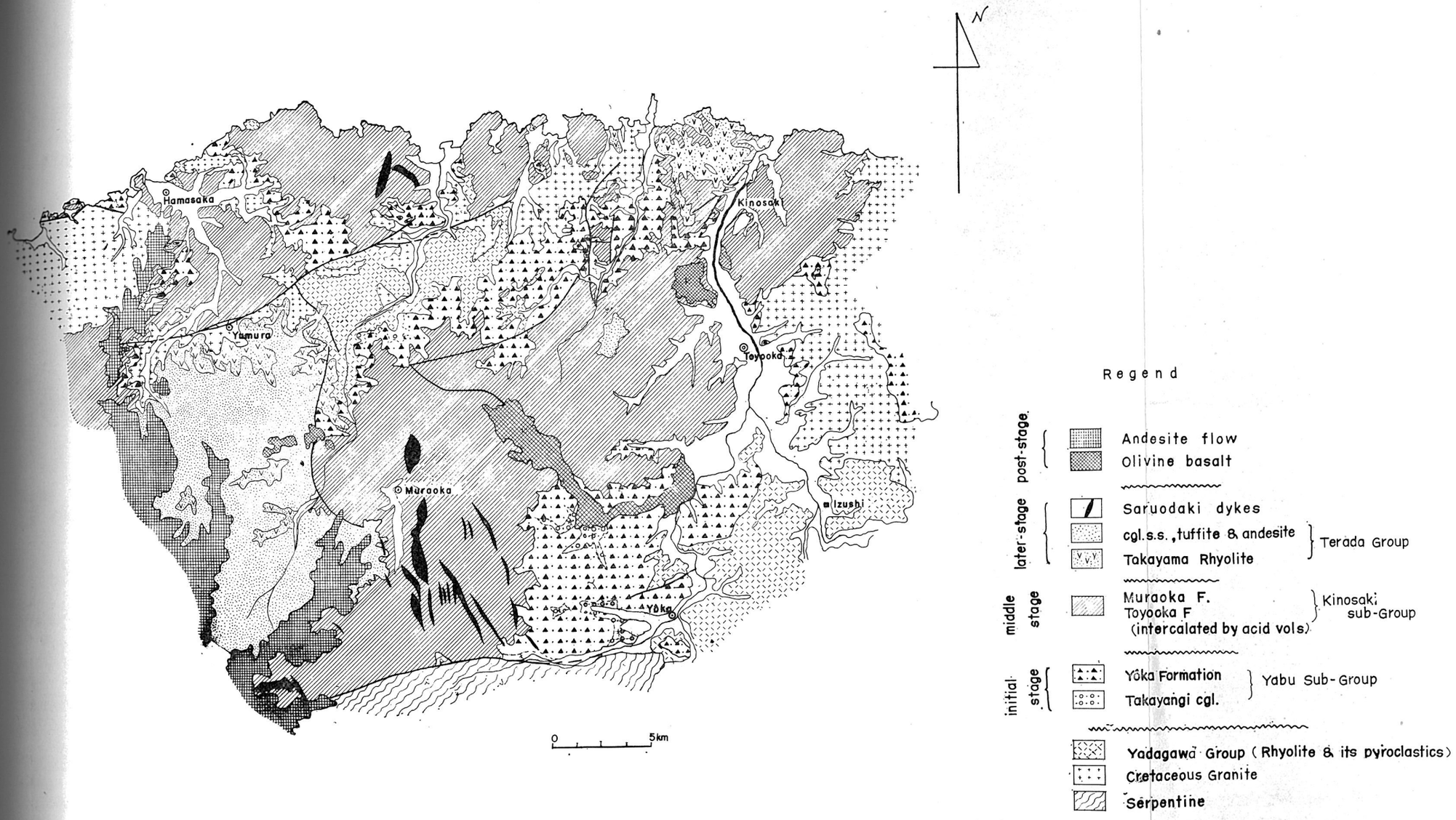

Fig. 13. Geologic Map of Hokutan Area by K. WADATSUMI & T. MATSUMOTO (1958.)